Strategies to manage tail biting in pigs housed in fully-slatted systems

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Declaration

I declare that I have composed this thesis. The work described is my own, I have made substantial contribution to the work, and all assistance received is acknowledged clearly in each introduction to the chapters. The work has not been submitted for any other degree or professional qualification. Any included publications are my own work, except where clearly indicated throughout the thesis about my own and the co-authors' contributions and summarised and clearly identified on the declarations page of the thesis.

Jen-Yun Chou

Abstract

EU Council Directive (2008/120/EC) prohibits the routine practice of tail docking to control tail biting in pigs, yet most pigs in Europe are still tail-docked. This is primarily due to a lack of effective solutions with the least economic impact for the producers, especially in fully-slatted systems. This PhD project aimed to find strategies to manage tail biting in pigs housed on fully-slatted floors, using enrichment and dietary strategies.

The first two experiments started with identifying suitable materials as enrichment for docked pigs housed in fully-slatted system. Pigs' enrichment use was compared between four different wood types; beech (*Fagus sylvatica*), larch (*Larix decidua*), spruce (*Picea sitchensis*) and Scots pine (*Pinus sylvestris L.*), and also between wood types (beech, larch, spruce) and a rubber floor toy. Pigs were consistently observed interacting with the spruce more frequently than the other wood types in the two experiments, and the rubber floor toy also generated a similar amount of interaction from pigs as the spruce post. No carcass damage was found which could be directly related to using dried wood sourced from a commercial sawmill.

The next experiment used a single enrichment item and different fibre levels in the diet to rear undocked pigs. In a 2×2×2 design, the pigs had either: A) a standard (weaner 3.7% finisher 5.9%) or high fibre (weaner 5.3% finisher 11.6%) diet; B) a spruce post or a rubber floor toy as enrichment in the weaner stage; C) the same/alternated enrichment given in the finisher stage. During this experiment a high level of tail biting was recorded (n=26 tail biting outbreaks), and a substantial number of pigs were removed temporarily or permanently from their home pens due to tail biting. Pigs fed with a high fibre diet had worse tail damage score and performed more tail biting. Pigs which had the floor toy in the weaner stage and wood in the finisher stage had slightly lower tail lesion scores. Pigs receiving the floor toy interacted with the enrichment more frequently overall. This study showed that higher dietary fibre in a relatively barren environment did not help reduce tail biting or tail lesions Moreover, a single enrichment item, which was

preferred by pigs in the previous studies, was not enough in a group of 14 pigs to control tail biting, and thus the quantity of enrichment may be important factor to consider.

In the final experiment, a 2 × 3 design was used to further investigate the effect of A) an enriched/barren environment during farrowing and B) three enrichment management strategies post-weaning, based on the frequency of replenishment ("Low": on Monday/Wednesday/Friday; "Medium": once daily; "High": *ad libitum*). All pens received the same enrichment (8 items/12 pigs, including an elevated rack supplied with fresh-cut grass). The average daily gain in the finishing stage was slightly higher in "High" than "Low" pigs. "Low" pigs also performed more damaging behaviours (tail/ear biting, belly-nosing, mounting, other biting and aggressive behaviours) than "High" and "Medium" pigs. No difference in lesion scores was found between treatments. Although sporadic tail biting outbreaks occurred (n=14, halved compared to the previous trial), they usually resolved within 2 weeks, and all but one tail-injured pig were successfully reintroduced back to their home pens after removals. Thus, this study concluded that by employing appropriate enrichment management strategies, tail biting can be kept at a level without a negative impact on the production cost in undocked pigs housed in a fully-slatted system.

Lay Summary

Tail biting is a damaging behaviour whereby pigs manipulate each other's tails, causing injuries and pain. In some cases, it could lead to spinal infection and premature death. It is a welfare issue for the pigs and also a production issue for the producers. There are many different causes of, and risk factors for tail biting that have been identified, and this makes it difficult to control. One risk factor is whether there is suitable "environmental enrichment," provided. This is material in the environment available for pigs to manipulate and root, which is an important part of their natural behaviour. Loose straw bedding has been considered the most effective material to reduce tail biting, but when the flooring system in the pig housing is slatted, (i.e. gaps in the floor to facilitate manure management), the provision of bedding is not practical, and alternatives are needed. One method that producers use to control tail biting is by cutting the pigs' tails shorter, and although this reduces the risk of tail biting, it doesn't eliminate it and only masks the underlying issues. This practice of "tail docking" has been banned in the EU as a routine method to control tail biting since 2008, however, still many pigs are tail docked due to a lack of practical solutions. This PhD project focused on finding feasible solutions to manage tail biting in undocked pigs housed in systems with fully-slatted floors, mainly by studying the effects of various types of environmental enrichment and dietary fibre.

The first task of the project investigated whether wood is a suitable material for pigs to use as enrichment. In the first two studies docked pigs were used. This was for two reasons: first, the main focus was to identify items which were favourable to pigs when there was a low risk of biting, and second, we wanted to assess the materials in conditions typical of most Irish farms. We also evaluated their effectiveness in reducing tail biting behaviours and tail lesions. The results showed that spruce attracted most interactions from pigs, probably because it is a softer type of wood. When the wood types were compared with a rubber floor toy, pigs interacted with spruce and the rubber toy with similar frequency. We did not find

injuries to the pigs that could be explained by splinters from wooden posts. We concluded that wood is a safe material for pigs, but a suitable wood type should be considered to encourage attracting the pigs' attention.

The second task was to rear undocked pigs by using a single enrichment item per 14 pigs, with either a high or standard fibre level in their diets. Based on the previous studies, we selected the spruce post and a rubber floor toy to use as enrichment items in this study. There was a high level of tail biting regardless of which item they were provided with or dietary fibre level. The pigs which had a higher dietary fibre level performed more tail biting behaviour and had slightly worse tail injuries. This could be due to the softness of their faeces because of the fibre, which made them dirtier and attracted other pigs' attention. A substantial amount of pigs had part of their tail shortened due to biting and needed to be removed temporarily for treatments. This showed that a single enrichment item and high dietary fibre are not enough to control tail biting in undocked pigs.

In the last task we provided pigs with multiple enrichment items that are compatible with slatted floors from 4 weeks of age onwards, including an elevated rack with fresh cut grass, hanging wooden blocks, rubber toys and fabrics, wooden posts, and floor toys. Although all pigs had the same number of enrichment items in their pens, different frequencies of replacing and replenishing the materials were investigated, and their effectiveness in controlling tail biting compared. Half of the pigs were also provided with items to manipulate earlier on, starting from one week after birth. This study showed that pigs with the least frequent replenishment performed more behaviours such as tail biting, ear biting and biting other parts of the body. They also gained less weight in the later stage of production compared to pigs with the most frequent replenishment. Although tail biting still occurred, the percentage of pigs with loss of tail and of pigs that needed to be removed for medical treatment was much lower than the previous study. This PhD project demonstrated that a complex enrichment strategy had a crucial role in reducing tail biting in undocked pigs in a fully-slatted floor system.

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Publications

Peer-reviewed journal papers included in the thesis

Chou, J.-Y., D'Eath, R.B., Sandercock, D.A., Waran, N., Haigh, A. and O'Driscoll, K., 2018. Use of different wood types as environmental enrichment to manage tail biting in docked pigs in a commercial fully-slatted system. Livestock Science, 213, pp.19-27 (**Chapter 3**)

Chou, J.-Y., O'Driscoll, K., D'Eath, R.B., Sandercock, D.A. and Camerlink, I. 2019. Multi-Step Tail Biting Outbreak Intervention Protocols for Pigs Housed on Slatted Floors. 2019. Animals, 9(8), p.582. https://doi.org/10.3390/ani9080582. (**Chapter 7**)

Other peer-reviewed journal papers published during the PhD

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Haigh, A., **Chou, J.-Y.** and O’Driscoll, K., 2019. An investigation into the effectiveness of compressed straw blocks in reducing abnormal behaviour in growing pigs. Animal, 1-10. doi:10.1017/S1751731119000715

Manuscript submitted for publication

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List of abbreviations

ADG	Average daily gain
ADFI	Average daily feed intake
DG SANTE	Directorate-General For Health And Food Safety
EFSA	European Food Safety Authority
Glimmix	Generalised Linear Mixed Models
TBO	Tail biting outbreak
TPPM	Teagasc Pig Production Model

Chapter 1 Introduction

"From this investigation it has become clear that the tail of a pig can be a very useful indicator of unpleasant surroundings." (Van Putten, 1969)

1.1 The issue: tail biting

Pig farming transformed dramatically since the turn of the 19th century, when pig production went through rapid intensification both in terms of utilising indoor confinement systems with a higher stocking density and a better quality of concentrated feed for higher growth and return (Hartung, 2013; Kittawornrat and Zimmerman, 2010). In continental Europe, the accelerated increase in the pig population began after World War II (Hartung, 2013), whereas in the United States the pig population has remained steady at around 30 – 50 million since the 1850s (Kittawornrat and Zimmerman, 2010), but the number of herds decreased after the 1960's which showed a concentration of the industry (USDA, 2008). In the meantime, pig housing also went through a change from mainly outdoor and extensive, to indoor housing (Mayda, 2004). Slatted flooring also came into use and has dominated since the 1960's (Mayda, 2004; Seerley et al., 1964, 1963) which accelerated the intensification of pig production. Many "abnormal" behaviours which developed along with this highly-intensified production trend were reported (Wiepkema et al., 1983), one of which is tail biting.

As early as 1959 tail biting in pigs had already been reported in the literature, and was attributed to overcrowding and poor management (Nesheim, 1959). In 1969, van Putten was the first to use experimental methods to investigate tail biting behaviour in finishing pigs. This study investigated the effect of ventilation and the absence or presence of a small amount of long straw on pigs' behaviours and tail injuries. It was found that poor ventilation could trigger tail biting, but the presence of straw greatly reduced the level of tail biting (Van Putten, 1969). However, tail biting only started to gain substantial attention at the turn of the century (using *Web of Science* search for tail biting in pigs: 14 results from 1970 to 1989, 25 results from 1990 to 1999, 58 results from 2000 to 2009, and 166 results from 2010 to 2019), possibly due to the prevalent use of tail docking as a control measure during this period (Sambraus, 1985; Schrøder-Petersen and Simonsen, 2001), and the growing awareness of farm animal welfare (Nalon and De Briyne, 2019). Over the past decade, the definitions, causes and risk factors of tail biting have been extensively reviewed (Brunberg et al., 2016; D'Eath et al., 2014; Edwards, 2011; Schrøder-Petersen and Simonsen, 2001; Sonoda et al., 2013; Taylor et al., 2010; Valros, 2018), and these will be summarised in the next section.

1.1.1 What is tail biting?

Tail biting is a damaging behaviour in pigs, and the literal definition is when a biter pig manipulates, chews and bites a recipient pig's tail. Brunberg et al. (2016) viewed tail biting as an "abnormal" behaviour in the sense that it is not commonly seen in the wild and is also less common when pigs are kept in extensive environments. The terminology of "tail biting" has been discussed among researchers (Taylor et al., 2010; Valros, 2018). In terms of the severity of tail damage induced, some studies referred to tail biting as any oral manipulative actions of the tail, such as tail-in-mouth behaviours, (Munsterhjelm et al., 2016; Schrøder-Petersen and Simonsen, 2001; Valros, 2018). Others only focused on a certain level of tail amputation caused by biting (McGlone et al., 1990), whereas Taylor et al. (2010) proposed to use an intermediate definition of "oral manipulation of the tail resulting in lesions." However, another practical issue that arises with this kind of definition is that it is difficult to ascertain the level of tail damage during behavioural observation.

Based on the description and development of tail biting behaviour, Taylor et al. (2010) proposed three types of tail biting: 1) "two-stage," when tail biting begins with mild non-damaging tail manipulation behaviours and gradually develops into damaging biting, 2) "sudden-forceful," when severe tail biting happens within a short time, usually by single or at times multiple biter pigs in a group, and 3) "obsessive," which usually involves one or few individual pigs performing tail biting also in a damaging and persistent manner that is difficult to stop. Valros (2018) also proposed a fourth type, "epidemic" biting, where tail biting happens suddenly due to an external factor such as a change in environmental temperature or feed and can spread from pig to pig, from pen to pen. These descriptions enable a view of the dynamics of tail biting behaviour, and in the next sub-section (**1.1.1.1**), it also helps with understanding the motivation behind tail biting and the risk factors surrounding it. However, it should be noted that these different biting types are likely to coexist and correlate among themselves, and can also be interchangeable. A biting event may start as "two-stage" and at some point become "sudden-forceful," and when it happens with a pig that is more persistent, it could become "obsessive."

Moreover, tail biting is a behaviour which involves two subjects, the instigator and the receiver, and the characteristics of both, and the interaction between the two, will also affect the development and the consequence of tail biting (Brunberg et al., 2016; Sambraus, 1985; Valros, 2018). The type of "obsessive" biting mentioned above is especially relevant since the biter pig may get rewarding feedback from performing this behaviour (Taylor et al., 2010). On the other hand, if the tail-bitten pig is unresponsive to biting or if the housing prevents it from avoiding it, the severity of tail biting behaviour may worsen (Taylor et al., 2010). Many studies have attempted to characterise traits such as weight, health status, immune function, stress level and behaviours of the biter and bitten pigs (Brunberg et al., 2016; Li et al., 2016; Munsterhjelm et al., 2013b, 2013a; Zonderland et al., 2011). However, the roles of the pigs can sometimes be fluid and difficult to identify (W. W. Ursinus et al., 2014a; Zonderland et al., 2008).

In terms of the age when tail biting occurs, different reports exist about when the behaviour is most commonly observed. Some studies recorded more tail biting during early weaner stage (6 – 8 weeks of age) compared to late weaner stage (9 – 12 weeks of age; Diana et al., 2017; Penny et al., 1981), whilst others suggested in general more tail biting in the finisher stage (from around 12 weeks of age onwards) than when the pigs were younger (Haigh et al., 2019; Lahrmann et al., 2017;

Schrøder-Petersen and Simonsen, 2001). However, there was also a report that more tail biting was recorded when pigs were 8 – 13 weeks of age in the late weaner stage compared to the finisher stage (O'Driscoll et al., 2013). During the finisher stage, tail biting was sometimes reported to happen more around 15 weeks of age (van de Weerd et al., 2005), whereas others observed it more in later stages of production when pigs are heavier (around 25 weeks of age; Scollo et al., 2013). This shows that the timing when tail biting occurs during production is unpredictable, but currently very few studies have reported that clear tail biting and damage occurred pre-weaning (before 3 - 4 weeks of age; Cox and Cooper, 2001; Ursinus et al., 2014).

As there are different definitions of tail biting available and used in the literature, Valros (2018) stressed the importance in identifying these differences when comparing results across studies. The different definitions used can imply a spectrum of severity of tail biting, and this will have profound impact when presenting results on the level of prevalence in different regions. Taylor et al. (2010) also suggested that the outcome and interpretation of research on tail biting prevention and intervention could be affected by the different categorisations of tail biting, and it requires a clearer definition. In this thesis, tail biting refers to any tail-in-mouth behaviours observed, since this definition can include a moderate spectrum of tail manipulative behaviours that may or may not result in tail lesions and is practical for observation. Combined with tail lesion scoring, a clear picture of the level and prevalence of tail biting can be obtained and assessed.

1.1.1.1 Why do pigs tail bite?

Schrøder-Petersen and Simonsen (2001) categorised the risk factors of tail biting into internal (related to the pig itself, e.g. genetics, gender, age, tail length and weight and health) and external ones (related to the environment and management practices, e.g. availability of materials for rooting, indoor and outdoor climate, stocking density, floor type, feeding system and the feed itself). D'Eath et al. (2014) also demonstrated the interconnectedness of these multiple risk factors behind tail biting, which makes it a difficult problem to solve. These risk factors are further associated with different motivations, which is crucial to understand in order to develop effective preventative strategies.

As different definitions of tail biting exist, there are also numerous theories of motivations proposed, which relate to each definition. The motivation behind "two-stage" biting is related to foraging behaviour, and for "sudden-forceful" biting, the motivation derived more from competition for a resource, whereas "obsessive" biting may be related to genetic or other predisposing factors which makes some pigs more prone to persistent biting (D'Eath et al., 2014; Taylor et al., 2010; Valros, 2018). For "epidemic" biting, it could be due to a sudden change in the environment, which will be discussed more in the next section (**1.1.1.2**). As previously argued, as the different types of tail biting can correlate and coexist among themselves, it is likely that the motivations behind can also co-evolve and interrelate with others. Since 1) this thesis mainly focuses on suitable foraging materials, which have been identified as one of the most important risk factors behind tail biting (D'Eath et al., 2014; EFSA, 2007), and 2) the definition of tail biting used in the thesis refers to any tail-in-mouth behaviours observed, therefore, the following discussion mainly focuses on the motivation related to "two-stage" biting in terms of pigs' exploratory and foraging behaviours.

Wild boars (*Sus scrofa*) are omnivores and spend half of the diurnal time foraging (D'Eath and Turner, 2009). As Stolba and Wood-Gush (1989) observed, when domestic pigs were released in a semi-natural environment, they retained many of the behaviours of their ancestors. Piglets in the semi-natural environment were observed to direct some chewing behaviours towards other pigs' body parts such as tails and ears when all other objects were occupied (Newberry and Wood-Gush, 1988). This exploratory behaviour is driven by both appetitive and intrinsic needs (Studnitz et al., 2007). The goal for appetitive needs can be consummated by feeding, whereas the aim of the intrinsic need is the curiosity for the surroundings and to perform investigation in order to understand the environment (Studnitz et al., 2007). In modern pig farming, the appetitive need to feed may be satisfied by the high-concentrated diet in commercial rearing conditions. However, the intrinsic motivation to forage still exists and needs to be performed (D'Eath and Turner, 2009; Duncan, 1998; Spinka, 2009). This shows the importance of the presence of suitable materials in pigs' housing, which should be edible, chewable, investigable, and manipulable (European Commission, 2016a). These properties are essential to stimulate pigs' exploratory motivation.

Regarding appetitive needs, another point for consideration is the pigs' natural instinct to feed together (D'Eath and Turner, 2009). However, in some commercial housing, feeding space is limited (either by timed feeding without enough space for all pigs to feed at the same time, or by *ad libitum* feeding but with limited-spaced feeder), and the appetitive need cannot be satisfied in time, which leads to tail biting (D'Eath et al., 2014; Taylor et al., 2010; Valros, 2018). Although the main function of available foraging materials targets the motivations for the "two-stage" biting, it may also alleviate "sudden-forceful" biting in this instance as a source of ingestible materials to divert feeding-motivated pigs' attention. It should be reminded again that the "typing" of tail biting only provides a better framework in understanding the motivations but not necessarily stays constant.

1.1.1.2 Tail biting outbreaks

Tail biting is difficult to manage not only because it is multifactorial, but because sometimes it tends to happen in a swift and sporadic fashion, and can quickly spread within an enclosure or a housing unit (Blackshaw, 1981; Edwards, 2011). Blackshaw (1981) suggested biting behaviours in pigs (tail and ear biting combined) could be spread through visual learning, although currently no evidence supports this hypothesis. It is yet known if audio (e.g. bitten pigs' screaming) or olfactory (e.g. smell of blood or fear) cues may trigger biting behaviours in pigs housed in neighbouring pens. This also relates back to the fourth type of "epidemic" biting proposed (Valros, 2018), which may be due to a sudden change in the environment, e.g. a malfunction in the ventilation causing the drastic temperature change in the housing or a disruption of the feeding system. However, another possibility is that the pre-injury stage of tail manipulation accidentally progresses into the stage which results in clear wounds and bleedings. The injured tails spill blood, and stimulate other pigs' interest in tails, even if they initially did not perform tail biting, and this escalates the problem (Taylor et al., 2010). This type of unpredictable and sometimes puzzling severe tail biting event is usually referred to as a "tail biting outbreak." More discussions on different definitions of tail biting outbreaks and how to assess them will be included in section **1.1.4.1**.

1.1.1.3 Consequences of tail biting

For the mild tail biting behaviours, in most cases there are either no lesions or no clearly visible bite marks on the tails, but there may be subcutaneous bruising (Simonsen et al., 1991). However, it can be difficult to distinguish whether it is from crushing by other pigs, sitting on the tail, or actually by tail biting. For more severe tail injuries, the skin is opened with possible bleeding wounds, and through the venous drainage the infection can spread to other parts of the body, especially into the vertebrae and lungs, which are commonly associated with a higher rate of carcass condemnation (Kritas and Morrison, 2007; Marques et al., 2012; van Staaveren et al., 2016). The most severe cases can even result in premature death (Schrøder-Petersen and Simonsen, 2001).

Besides the direct pathological consequences of tail injuries and infection, tail biting also results in a heightened stress level, reduced weight gain, lameness and other health issues in bitten pigs (Valros, 2018). Slaughterhouse surveys showed that tail lesions have been associated with reduced carcass weights and a higher percentage of carcass condemnations, which brings economic loss to the producers as well (Harley et al., 2012; Kritas and Morrison, 2007; Valros et al., 2004). Thus tail biting is not just a welfare issue for the animals; it is also a production issue for the farmers.

As pig production moves towards more intensive systems, this can increase the occurrence of tail biting (Kittawornrat and Zimmerman, 2010). In addition, one of the most commonly used method to control tail biting, tail docking, has been under scrutiny and will be discussed in the next section (**1.1.2**)

1.1.2 Pressing issue: phasing out tail docking

One reason why tail biting has now become the centre of attention in research and discussion among stakeholders is that it has been controlled to a great extent by tail docking possibly since the 1970’s (Anonymous, 1970; Brent, 1982; Larsen, 1983; Sonoda et al., 2013). A pig production handbook published in the United States in 1956 stated that the market then preferred pigs with tails and tail docking was not recommended, and all pictures of pigs in the handbook were with intact tails (Bundy and Diggins, 1956). Tail docking is a procedure which involves removing by amputation a portion of the tail (typically one to two-thirds of the distal tail, depending on different practices); commonly with a sharp knife, cautery iron or rubber rings (Sutherland et al., 2008), usually done within 2 to 5 days post-partum. It is often practiced by a trained stockperson without pain relief, unless performed after 7 days of age (De Briyne et al., 2018).

Studies suggested that tail docking is effective in controlling tail biting because docked tails have increased sensitivity and lead to a quicker response when pigs are bitten (Herskin et al., 2015; Simonsen et al., 1991), although the evidence is not unanimous (Sandercock et al., 2011). Other possible explanations are that the shortened tails become more difficult for other pigs to access and bite (Paoli et al., 2016) or are less appealing due to their shape and lack of a tuft of hair at the tip (Feddes and Fraser, 1994; Simonsen et al., 1991). It has been an effective procedure in reducing the risk of tail biting. Indeed, several studies have found that undocked pigs had higher tail lesion scores and more frequent tail biting behaviours than docked pigs (Di Martino et al., 2015; Hunter et al., 2001; Lahrmann et al., 2017; Li et al., 2017; Sutherland et al., 2009; Thodberg et al., 2018), and pigs with long-docked tails also had higher lesion scores than short-docked pigs (Sutherland et al., 2009; Thodberg et al., 2018). Through carcass inspection, similar results were found that undocked pigs in organic or free-range herds still had a higher prevalence of tail lesions than docked pigs in conventional herds (Alban et al., 2015; H. Kongsted and Sørensen, 2017). As a preventative measure to tail biting, Larsen et al. (2018) reported tail docking was twice as effective than the provision of long straw or a lower stocking density.

However, tail docking does not completely eliminate tail biting (Harley et al., 2012; Hunter et al., 2001; Kritas and Morrison, 2004; Li et al., 2017; Sutherland and Tucker, 2011; Thodberg et al., 2018). Within Europe, the prevalence of tail biting (showing clinical sign of tissue damage) ranges from 2-12% in undocked pigs and about 3% in docked pigs, depending on different definitions of tail lesions recorded (Valros and Heinonen, 2015). In a surveillance report conducted from slaughterhouse visits in the Republic of Ireland and Northern Ireland, although 99% of the pigs' tails were docked, the prevalence of observable tail lesions was almost 60%, with 1% of severe tail lesions observed (Harley et al., 2012), suggesting that some level of tail biting still exists. Bracke et al. (2012) introduced a "tilting bucket" theory, which pictures the bucket of tail biting placed on a slope, containing all the possible risk factors behind it as liquid content in the bucket. As a risk factor increases, the chance of the liquid overflowing (some level of tail biting) or eventually tilting the bucket (tail biting outbreak) goes higher. Under this theory, tail docking is only decreasing one of the bucket's contents without addressing all other factors. What may be worse, by practising tail docking, farmers could overlook other factors (such as manipulable materials, ventilation and stocking density) and solely count on tail docking to prevent tail biting, which masks the issue of overall poor rearing conditions and impaired pig welfare.

Moreover, studies have shown that tail docking in neonatal pigs induces an acute stress responses (Marchant-Forde et al., 2009; Sutherland et al., 2008), impairs piglet's growth pre-weaning (Marchant-Forde et al., 2009) and produces long term negative neurological consequences (Herskin et al., 2015; Sandercock et al., 2019, 2016; Sutherland, 2015). Based on the opinion of the Scientific Veterinary Committee, EU Council Directive 91/630/EEC stated that routine tail docking should not be carried out unless there is evidence on farm that tail injuries have occurred (European Commission, 1991). Nevertheless, the progress of implementing the ban on routine tail docking has been slow (Nalon and De Briyne, 2019), and tail docking is still widely practiced in many EU countries, usually because most farmers can point to veterinary advice that it is best for pig welfare in their system (De Briyne et al., 2018). In 2014, as a result of a citizen petition raised by the Danish Animal Welfare Society in 2012, the European Commission aimed to conduct stricter enforcement of the tail docking ban and prepare for infringement announcement and further actions (Marzocchi, 2014). Early in 2015, Germany, Denmark, Netherlands and Sweden, four major pork production countries in the EU, signed a declaration paper to significantly reduce the percentage of tail docked pigs (General Secretariat of the Council, 2015). The pressure from the public and campaign groups has been gathering, and the European Commission recently reiterated its position on enforcement of the tail docking ban, with possible infringement procedures imposed on non-compliant countries soon (Chou and Costa, 2019; Nalon and De Briyne, 2019). Finding alternatives to tail docking in controlling tail biting has become an even more pressing issue now.

1.1.3 Beyond tail biting

Some other behaviours can also be associated with tail biting. In many studies, ear biting was observed alongside tail biting (Blackshaw, 1981; Haigh et al., 2019; Smulders et al., 2008; Telkänranta et al., 2014a) and similarly for flank biting (Brunberg et al., 2016; Petersen et al., 2008; Schrøder-Petersen and Simonsen, 2001). However, there has not been as much research on ear and flank biting as on tail biting. Ear biting or ear lesions have been reported to be an issue on farm (Diana et al., 2019; Petersen et al., 2008; Van Staaveren et al., 2018), and studies have suggested it shares similar risk factors as tail biting (Brunberg et al., 2016; Schrøder-Petersen and Simonsen, 2001; Smulders et al., 2008; Sonoda et al., 2013; Taylor et al., 2010; Valros, 2018). A study has found ear biting happened more frequently when pigs' tails were short-docked (Goossens et al., 2008), although evidence is not conclusive (Taylor et al., 2010). Ear biting can also become a prelude to aggression and stimulate an agonistic reaction from the receiver pig as it is a head-to-head encounter (Jensen, 1980). On the other hand, ear lesions themselves can be accumulated during aggressive encounters (Turner et al., 2006). Ear necrosis, a bacterial infection that causes tissue damage on the ear, is also associated with ear lesions (Diana et al., 2019; Quinn and O'Driscoll, 2016; Weissenbacher-Lang et al., 2012). Ear biting can be interconnected with ear necrosis, either as a cause or a result of it.

Flank biting seems less prevalent than tail or ear biting (Petersen et al., 2008), but this could also be due to a lack of records. There was suggestion that it could be a result of aggression (van Staaveren et al., 2015), while others suggested that flank biting is more related to tail biting (Brunberg et al., 2016; EFSA, 2007; Schrøder-Petersen and Simonsen, 2001; Spoolder et al., 2011). Flank lesions can also be caused by repetitive belly-nosing (Torrey and Widowski, 2006). Belly-nosing is a nosing behaviour by pushing up and down rhythmically, usually targeting the recipient's abdominal area, sometimes accompanied by sucking behaviour (Bench and Gonyou, 2007; Straw and Bartlett, 2001; Torrey and Widowski, 2006; Widowski et al., 2008). Some suggested it is a symptom of pigs' nutritional need immediately post-weaning (Torrey and Widowski, 2006; Widowski et al., 2008), others have related it to weaning age (also linked to suckling need), genetics and the availability of foraging materials (Straw and Bartlett, 2001, Widowski et al., 2008). Similar to ear necrosis, flank lesions create route for bacterial infection and can lead to severe ulceration and skin erosion (Mirt, 1999). Whereas ear lesions are usually observed during earlier weaner stage (5 – 10 weeks of age, Diana et al., 2017; Quinn and O'Driscoll, 2016; Weissenbacher-Lang et al., 2012), flank lesions are observed to appear at all ages (6 – 20 weeks of age, Mirt, 1999).

As these behaviours are partly related to tail biting, they are included in the discussion and evaluation of the thesis.

1.1.4 Evaluating tail biting outcomes

Despite the urgency of finding solutions to manage tail biting, it is a topic difficult to study and replicate due to its unpredictable nature, and sometimes results in inconsistent reports (D'Eath et al., 2014). As discussed in section **1.1.1**, not only are there different definitions of tail biting, the measures used to evaluate the outcome also vary between studies (see reviews by Brunberg et al., 2016; D'Eath et al., 2014; Schrøder-Petersen and Simonsen, 2001; Sonoda et al., 2013; Taylor et al., 2010; Valros, 2018). Lesions, such as tail, ear and flank lesions are the most commonly used indicators to assess the effectiveness of prevention strategies (D'Eath et al., 2014). In addition, the prevalence of tail biting outbreaks was sometimes used as an assessment criterion (Lahrmann, 2018; Statham et al., 2011; van de Weerd et al., 2006, 2005; Zonderland et al., 2008). In some studies, the number of animals affected by, or removed due to, severe tail biting was also used as an indicator (Beattie et al., 2001; Scott et al., 2006a, 2007a; van de Weerd et al., 2005, 2006).

Besides lesion scores, behaviour observation is a common measure for evaluation. Depending on the definition of tail biting and methods of observation, there may be different levels of tail manipulative behaviours recorded, such as nosing tail (Fraser et al., 1991), tail-in-mouth (Munsterhjelm et al., 2016; Schrøder-Petersen et al., 2004), chewing and biting tails (van de Weerd et al., 2005) or any tail-directed behaviour (Amdi et al., 2015; Lahrmann et al., 2015). The previous section (**1.1.3**) also discussed ear and flank biting, and belly-nosing as other commonly included behaviours for assessment. Some studies combined all these behaviours as a composite of damaging behaviour (Telkänranta et al., 2014a; van de Weerd et al., 2006).

Physiological indicators of stress, such as cortisol level in blood, saliva, hair or faeces, is sometimes included as an additional indicator either directly linked to tail biting (Munsterhjelm et al., 2013a; Palander, 2016), or used to evaluate other parameters involved in the prevention of tail biting, such as environmental enrichment or stocking density (Cornale et al., 2015; de Jong et al., 1998; Giuliotti et al., 2019; Haigh et al., 2019; Nannoni et al., 2016; Scollo et al., 2013; van der Staay et al., 2017).

Another assessment measure is through tail scoring during carcass inspection. This is a common method especially in prevalence studies (Harley et al., 2014; Kritas and Morrison, 2007; Valros et al., 2004; van Staaveren et al., 2016; vom Brocke et al., 2019). However, tail lesions on the carcass may underestimate the severity of tail biting due to healing or when pigs did not reach the slaughterhouse due to premature deaths or euthanasia (Taylor et al., 2010), thus it is more suitable as an additional measure.

1.1.4.1 Assessing tail biting outbreak interventions

Similar to the definition of tail biting, the term tail biting outbreak has also various definitions. It has been used commonly in literature to describe a spectrum of severe tail biting incidences. Lahrmann (2018) listed more than ten definitions of tail biting outbreak in the existing literature, and it has become clear that the terminology has been used in an extensive way. For example, in Li et al. (2016), an outbreak was referred to as whenever blood was visible on a tail, and Larsen et al. (2016) used “tail damage outbreak” to denote the presence of freshly bleeding tail wounds. These definitions are not distinguishable from a moderate level of tail biting, but it also highlights the difficulty in defining a tail biting outbreak without a clear cut-off point.

More specifically, Statham et al. (2009) classified outbreaks into underlying and severe based on clinical signs of tail damage. Underlying outbreaks were only determined during close tail inspection (without specified criteria), whereas severe outbreaks were when two out of 30 ± 9 pigs in a pen had tail amputation or when blood was present in a pen. In Van de Weerd et al. (2005), they defined outbreaks as when three or more pigs out of a group of 13 – 16 pigs had fresh tail damage and tail biting behaviour did not stop without intervention. However, these definitions were still ambiguous in terms of the criteria of the freshness of tail wounds and how to determine the status of on-going tail biting behaviours. More recent studies used specific tail lesion scores along with a specific percentage of pigs affected to define a tail biting outbreak (Lahrmann et al., 2019; O'Driscoll et al., 2013; Wedin et al., 2018; Zonderland et al., 2008), which is necessary in order to study how effective the different intervention methods can be during tail biting outbreaks. The outcome of the interventions should also be evaluated according to the definitions given (Lahrmann, 2018). In this thesis, the definition of tail biting outbreak is when three or more pigs in a group of 12 to 14 pigs have fresh blood or severe tail wounds according to the tail scoring scale used. On commercial farms, farmers do not conduct individual tail scorings inside the pen but rely on checking the pigs from outside the pen, which implies that they tend to identify tail biting outbreaks at a later stage. In order to assess intervention methods that could be practically applied, a definition of a more advanced stage of tail biting outbreak was selected than in some of the previously published studies.

As explained in section **1.1.1**, this thesis uses a practical definition of tail biting as any tail-in-mouth behaviours during observation. Along with the tail lesion scores recorded from live pigs and carcasses, they are the main methods used to understand the severity and prevalence of tail biting occurring and to evaluate the effectiveness of the tail biting management strategies proposed to reduce the level of tail biting. In study 2 (**Chapter 4**), salivary cortisol is used as a supplementary measure. In the next section (**1.2 and 1.3**), feasible preventative solutions compatible with the fully-slatted system are discussed, mainly focusing on the provision of "environmental enrichment," which will be reviewed in detail in section **1.2**, with section **1.3** focusing on the possible effect of high dietary fibre.

1.2 Environmental enrichment

Environmental enrichment originated from the study of zoo animals which are kept in the captive environment for a prolonged period of time, with some animals developing stereotypic behaviours (Young, 2003). According to Shepherdson et al. (1998), who gave environmental enrichment a complete conceptual framework, it is a "husbandry principle that seeks to enhance the quality of captive animal care by identifying and providing the environmental stimuli necessary for optimal psychological and physiological well-being.” Newberry, (1995) used a simpler but equally essential definition that it should “improve the biological functioning of the animals,” i.e., improve the animals’ health and promote species-typical behaviours that help animals adapt to their living environment, and improve their welfare. It is therefore important to understand which species-typical behaviours enrichment can stimulate, and in what way can enrichment help improve the animals’ welfare.

Since the late 1990’s, research on enrichment has grown exponentially according to a GAP analysis of all literature on environmental enrichment from 1985 to 2004 (de Azevedo et al., 2007), and although agriculture is not the main discipline that has invested in enrichment studies, in terms of the animals in focus, farm animals were only next to laboratory animals, among which the studies on pigs took the majority. In general, across species, there are different methods of utilising environmental enrichment, and predominantly it is done by modifying the physical structure of the enclosure (Newberry, 1995; de Azevedo et al., 2007). In zoo animals, there can be greater flexibility in terms of enriched feeding and sensory stimulations compared to farm or lab animals (Clark and King, 2008; de Azevedo et al., 2007; Newberry, 1995). In comparison, many farm animals are housed in intensive and monotonous indoor conditions, and providing enrichment devices to improve the housing complexity is the most common and applicable method in commercial settings (Averós et al., 2010; de Azevedo et al., 2007; Mkwanazi et al., 2019; van de Weerd and Day, 2009). However, it is commonly misunderstood that simply introducing additional objects into the animals’ surroundings constitutes “enrichment,” without careful evaluation as to whether the device provided has biologically meaningful value to the animals in question.

Additionally, Newberry (1995) stressed the importance of having a clear goal in order to define the biological relevance to the animals when providing enrichment. For example, most enrichment studies for gestating sows have focused on alleviating hunger-related stereotypic behaviours since in commercial production sows are constantly restricted-fed in order to prevent them from becoming over-weight (D'Eath et al., 2018). On the other hand, for growing pigs the target of enrichment is mainly to reduce stress, improve performance, and prevent damaging behaviours, which is the focus of the current thesis. Since the motivation to forage is the main cause behind the most commonly reported "two-stage" biting as discussed in section **1.1.1.1**, when foraging materials are absent, this motivation is likely to be directed towards other pigs, such as biting tails. Additionally, many studies have identified the absence of biologically relevant manipulable materials as the main risk factor on farms (Grümpel et al., 2018; Kallio et al., 2018; Moinard et al., 2003; Taylor et al., 2012). Under this line of reasoning, the primary function of enrichment should be as a meaningful medium for pigs to manipulate that can meet their foraging need, although it may also help with thermal regulation, environmental comfort, reduction in competition for food and nutritional benefits, which are all underlying risk factors for tail biting (D'Eath et al., 2014).

Van de Weerd et al. (2003) used a systematic approach to investigate growing pigs' preference for different enrichment items from an extensive list. In this pioneering paper, the authors classified point-source items, which are non-particulate objects and usually restricted in size or location in the pen relative to loose bedding material (van de Weerd et al., 2009), into different properties and traits based on the behavioural activities the pigs can engage in. They reported the highest ranked traits of enrichment to sustain pigs' interest as being "ingestible" and "destructible," which corresponds to their behavioural needs during foraging. In the latest European Commission recommendations regarding measures to reduce the need for tail docking, it also stated that pigs should have access to enrichment materials that are "edible," "chewable," "investigable" and "manipulable" (European Commission, 2016a). Furthermore, in the staff working document accompanying this EC recommendation (European Commission, 2016b), enrichment was further categorised into "optimal" (mainly bedding substrates such as straw and hay), "suboptimal" (primarily point-source organic items or loose substrates supplied via a dispenser), and "marginal" (namely inorganic items such as chain and hanging plastic toys). These different properties are important to consider when choosing suitable enrichment for pigs.

Currently, straw is still regarded as the gold standard of enrichment material for pigs in terms of satisfying pigs' behavioural needs and has been extensively researched (Bracke, 2006; Tuyttens, 2005; van de Weerd and Day, 2009). Many studies have also established a positive link between the provision of straw and substantially lower risk of tail biting (Brunberg et al., 2016; Bulens et al., 2015; Day et al., 2002; de Jong et al., 1998; Scollo et al., 2013; Taylor et al., 2010; van de Weerd et al., 2005; Zonderland et al., 2008). However, there are practical issues that prevent straw from being used widely, which will be discussed next.

1.2.1 Why is straw not used?

Enrichment provision is not purely related to the issue of tail biting, but is in itself a general legal requirement in the EU (European Commission, 2016a). Loose straw provided on the floor has been identified to be the most suitable and effective substrate for pigs (EFSA, 2007; Spoolder et al., 2011; Tuyttens, 2005), however, the prevalence of straw provision in EU is still low (De Briyne et al., 2018). One of the main reasons is the slatted flooring system, which is still the most commonly used around the world and in Europe (EFSA, 2005). In this system, there are gaps in the floors (1.1 cm for piglets, 1.4 cm for weaners and 1.8 cm for finishers) to facilitate manure removal from the surface to a collection tank and drainage system underneath the flooring, where the liquid slurry can also be removed from site efficiently, usually via vacuum pumping (Ryan and Brett, 1999). This system benefits maintenance of hygiene and can reduce risks of enteric diseases caused by faecal residues (EFSA, 2005); however, it limits the use of bedding materials. Provision of long straw becomes problematic since, firstly, it can obstruct the manure from passing through the gap regularly and create hygiene problems. Zonderland et al. (2008) reported blocked slats when as little as 20g/pig/day of long straw was provided on the floor in a partly-slatted system. Secondly, if long straw falls through the slats and enters the slurry tank, it can further clog the pipes during vacuum pumping. Although this latter issue is widely reported (Day et al., 2008; D'Eath et al., 2016; EFSA, 2007; Lahrmann et al., 2015; Scott et al., 2007b; Wallgren et al., 2016; Zonderland et al., 2008), surprisingly no research found focuses on detailing how the mechanism of blockage develops. On the other hand, there are studies suggesting that this issue may be resolved if appropriate filters, choppers or scrapers are installed, but these are seldom used and not proven completely successful in preventing blockage (Ryan and Brett, 1999, Wallgren et al, 2016).

If the materials are composed of smaller particles (such as sawdust and fined-chopped straw), the blockage of slats may be alleviated (Westin et al., 2013). Some studies suggested that using 25 g/pig/day of chopped straw can alleviate the issue of manure blockage in partly-slatted systems and kept tail-directed behaviours at a low level (Amdi et al., 2015). On the other hand, Day et al. (2008) found more tail manipulation and less straw-directed behaviours with chopped straw than long straw, whilst Lahrmann et al. (2015) showed they performed equally well in terms of enrichment interaction, tail directed behaviours and tail lesion scores on partly-slatted floors. Another method is to reduce the amount of straw provision. Zonderland et al. (2008) used long straw dispensed from a feeder in a partly-slatted system where the pigs only consumed about 5 g/pig/day, which did not cause hindrance to the slurry system and reduced tail wounds compared to other less effective enrichment items (chain and rubber hose). However, in fully-slatted systems the issue is more serious since once materials of smaller particles fall through the slats easily, it can still potentially block the slurry when combined with faeces. There are other materials identified to be attractive to pigs (Jensen et al., 2008; Jensen and Pedersen, 2007), such as hay, grass, peat and silage, which may be less disruptive to the liquid slurry system, that need to be investigated further.

Other than the blockage of the slurry system in slatted housing, straw may not be suitable in a hot climate (Fàbrega et al., 2019) and also dramatically increases production cost where straw is not easily available. The distribution of fresh straw and the removal of it once it is soiled creates additional workload which requires more labour and cost. Economic constraints and a lack of incentive are identified to be the main obstacles to the implementation of adequate enrichment in commercial production systems (de Azevedo et al., 2007; D'Eath et al., 2016). As practicality is another important element to consider when designing and assessing enrichment (Newberry, 1995), it is crucial to find an economically feasible and effective solution on commercial farms that can be translated into farmers' practices.

In the following sections (**1.2.2 to 1.2.5**), current knowledge regarding enrichment materials which may be possible alternatives to straw will be reviewed. As the focus for this PhD thesis is to manage tail biting as a negative and damaging behaviour with strategies practical to the producer, it therefore adopts a broad definition of environmental enrichment as any improvement to the current captive environment that may benefit the animal, especially at preventing damaging behaviours. When using the term "enrichment," it may not go beyond preventing the negative towards promoting the positive such as improving the biological functions of the animals as defined by Newberry (1995). The focus is on the materials that can be compatible with the fully-slatted system.

1.2.2 Wood

Wood is a commonly used organic material which is provided as environmental enrichment for pigs, especially in housing systems where having loose substrates on the floor is not possible (Spoolder et al., 2011). In the above-mentioned EC staff working document on best practices in providing enrichment materials for pigs, it classified wooden materials as "suboptimal," and stated that they can be used as essential items as long as they are provided along with other materials (European Commission, 2016b). According to an Irish survey on farmer's attitudes towards enrichment and tail biting (Haigh and O'Driscoll, 2019), wood was considered a useful and economical enrichment to reduce tail biting. In that survey, the most important traits of enrichment for the farmers are its effectiveness to reduce tail biting and its durability, followed by the impact on the slurry system and cost.

1.2.2.1 The generic wood?

Although wood is usually referred to as a homogenous entity when presented as environmental enrichment for pigs in many studies (Beattie et al., 1998; Tönepöhl et al., 2012; Trickett et al., 2009; Zonderland et al., 2003), there are actually numerous wood species that have different properties when it comes to levels of hardness, moisture, texture, and their odour (Forest Products Laboratory, 2010; Wang and Wang, 1999). These properties may cause different responses from pigs due to their distinct sense of olfaction and gustation (Kittawornrat and Zimmerman, 2010). Nowicki et al. (2015) have demonstrated that pigs can react differently to various aromas. Another important feature of wood that could affect pigs' interaction is the hardness. Wood is classified into "softwood" and "hardwood" based on the tree's reproductive traits, rather than the actual hardness (Forest Products Laboratory, 2010; Froberg-Fejko and Lecker, 2012). Indeed some softwood species can be physically harder than hardwood species (Forest Products Laboratory, 2010; Froberg-Fejko and Lecker, 2012). A common misconception exists that these terms are used to describe wood types with differing hardness, while the actual properties of the wood species are usually overlooked (Bracke, 2006; Bracke and Koene, 2019).

Most research using wood as enrichment for pigs compares wood with other point-source enrichment items, usually of inorganic materials, or compares between different presentations of the wooden items. Zonderland et al., (2003) presented groups of eight finishing pigs (24 – 28 kg of bodyweight) with either a rope, a wood log, a chain or a pipe, either hanging vertically or horizontally. More interactions were recorded with rope compared to all other items, but the orientation made no difference. Elkmann and Hoy (2009) compared three different methods of presenting wood blocks (single long post suspended horizontally, four short blocks dangled as a cross swing or one short block attached horizontally to a metal pipe) to groups of nine finisher pigs (33.1 – 119 kg), either housed on concrete floor with straw or slatted floor without bedding. They found the cross swing attracted more interactions from pigs, and that pigs without access to straw used the wooden items more than pigs with straw. Trickett et al. (2009) compared suspended rope and loose wood blocks on the floor. Weaners (4 – 8 weeks of age) in groups of 10 either had continuous access to two ropes, one wooden block on the floor, weekly alteration between rope and wood or continuous access to both rope and wood. Pigs always showed more interaction with rope than wood and performed less manipulation of their pen mates when rope was present. The authors reported that the loose wood block on the floor was easily soiled and needed to be cleaned daily, which could be the reason why pigs did not interact with it as much as the hanging rope. Farmers reported pigs interacted with horizontally-hanging wood blocks more than wood posts dispensed vertically in a wall-mounted cylinder which allows the wood post to touch the ground (Canning et al., 2013). They also reported soiling issues with the wood post. When soft wood, hard wood, rubber pipe and different types of rubber dog toys were offered suspended in the pen, a large rubber dog toy was used more by the pigs (Canning et al., 2013). These studies demonstrate that wood is not always preferred, even when compared to inorganic items, but the presentation of the wood can influence the outcome. However, all of the above-mentioned studies did not specify the wood species they used, and so it is difficult to accurately evaluate its effect on pig behaviour or comparison to other items.

In terms of health and safety issues, (Barbari et al., 2017) reported that when selecting wooden materials, whether a species is toxic, has thorns and spikes, or requires constant pesticide treatments during cultivation should be considered. There are suggestions that older and dried wood could cause splinters (European Commission, 2016b) whilst others mentioned more splinters from soft pine wood (Nowicki et al., 2018). Bracke et al. (2006) also raised concern about possible intestinal punctures by sharp wood pieces. The speculation of the risk expressed was most likely based on anecdotes or human experiences with wood splinters, without scientific evidence to support it (Haigh and O'Driscoll, 2019). Nevertheless, these raise concerns over potential injuries that could be caused by wood splinters to the pigs and therefore merit further investigation, before confirming the suitability of wood as an enrichment material for pigs.

1.2.2.2 Different species of wood

In research on wood as enrichment material for small animals, such as meat rabbits and laboratory rodents, different species of wood are usually specified and compared. These studies focused on the physiological impacts that the amount of wood consumed had on the animals, which is potentially greater than large animals due to their smaller body volume. A study found that softwood bedding such as red cedar (*Thuja plicata*), white pine (*Pinus strobus*) and ponderosa pine (*Pinus ponderosa*) induced drug-metabolising enzymes in mice and rats, and a reversed effect when hardwood bedding like beech, birch (*Betula*) and maple (*Acer pseudoplatanus*) was used (Vesell, 1967). Other authors reported that softwood sticks may contain aromatic hydrocarbons that can be hazardous to the liver function of rodents and rabbits after a prolonged period of consumption (Froberg-Fejko and Lecker, 2012). No other negative effects on the carcass resulting from using different wood species (i.e. wooden sticks) as enrichment have been reported in meat rabbits (Jordan D. et al., 2008; Jordan and Štuhec, 2002; Kermauner et al., 2004). Pigs may not be affected physiologically as much as rodents and rabbits by consuming wooden enrichment due to their larger body mass; however, it is important to investigate if there are similar effects on physical and visceral deterioration in pigs from consuming wood.

Telkänranta et al., (2014a) was the first experimental study to compare the effectiveness of a specific wood species with other materials as environmental enrichment for pigs in relation to damaging behaviours and interaction. The authors used undocked finishing pigs (from 8 weeks of age) housed in a group of ten pigs on 25% partly slatted floors, and all pigs had access to a chain, weekly replenished straw in a rack, and a daily supply of wood shavings on the solid floor area. They further compared between fresh branches of birch (*Betula pendula* and *Betula pubescens*), polythene pipes in a cross shape, branched chains, all three items combined or none of the above as additional enrichment devices. All items were suspended from the side of the pen. Overall, interactions with point-source items (excluding the straw rack) were higher in pens with wood, pipe or all three items, and pigs interacted with wood more than chain among the three items. The frequency of pigs' damaging behaviours (tail/ear/flank biting, biting other body part and belly-nosing) did not differ between treatments, but more pigs had no damage scored on ears and tails when wood was present in the pen. This study has shown that by providing a fresh wood branch as an additional point-source enrichment item, as well as a small amount of loose materials, it could lower the occurrence of tail and ear lesions, albeit with no difference in damaging behaviours. Although there were pigs removed from the trial due to severe tail damage, the level of tail biting reported was low (46% of undamaged tails and 30% of mild tail damage recorded). However, due to the presence of a combination of different items, the effect of wood itself as environmental enrichment was inconclusive. Using fresh branches of wood also creates more difficulty in standardisation and comparison than wood sourced from sawmills since they contain bark and twigs.

In a study looking at the effect of stocking density and enrichment on pig behaviour and stress level, Cornale et al., (2015) compared between finishers (15 – 31 weeks of age) housed in barren pens and the ones provided with two suspended locust wood (*Robinia pseudoacacia L.*) pieces, under high or low stocking densities (a group of 13 or 19 in the same sized pen of 19.76 m^2). Pigs provided with wood spent less time lying and performing tail biting and aggressive behaviours. Faecal corticosteroid concentration was suggested by the authors as a measure of chronic stress in pigs; however, no difference in this measure was found between enrichment treatments, only between different group sizes/stocking densities.

Nannoni et al. (2016) compared different enrichment items for undocked weaner pigs (4 – 11 weeks of age), housed on fully-slatted floors in groups of five. They were offered either a hanging chain or a poplar (*Populus*) log fixated horizontally in the pen. No statistical difference in the enrichment interactions, tail biting behaviour or tail and body lesions was found between chain and wood, but the duration of interaction tended to be higher with wood. The authors also assessed hair samples for cortisol level and blood samples for various biochemical and metabolic parameters, such as markers of energy and protein metabolism, liver function, oxidative stress and immune response, to assess the overall health status and stress level of the animals. There was no difference in hair cortisol level. Although conflicting results were found in the plasma biomarkers, there was no indication of damage to liver functions in any of the pigs. The same authors further compared a hanging chain with three poplar logs supplied in horizontal racks to finishing pigs (27.1 – 158.4 kg of bodyweight, Nannoni et al., 2018), and found that pigs with wood had worse tail lesions and less frequent interactions with the enrichment, albeit with longer interaction bouts. No difference in blood parameters was found between pigs with chain or wood to suggest signs of impaired health.

As these more recent studies have shown, not only does wood have the potential to be further explored as environmental enrichment for pigs, the species of wood used has also started to be reported. However, these studies did not report measurements on the wooden items, thus, it is difficult to evaluate to what extent pigs were able to destroy or ingest them. Moreover, no study to date has attempted to compare between different wood species, and how this may affect pigs' use is still unknown. This is one of the important focus' of this PhD thesis.

1.2.3 Loose materials in a fixed location

The advantage of loose materials is their "particulate" nature (van de Weerd et al., 2003), i.e. they can be spread around the pen through manipulation by the pigs. As Fraser et al. (1991) and Zwicker et al. (2012) both observed, when substrates were provided via dispensers, they dropped on the floor through pigs' manipulation, working as a "self-replenishment" mechanism so that more pigs can explore them. On slatted floors, this is an important consideration, since it may sustain pigs' interest for a longer period of time compared to other non-particulate point-source items. However, overflowing of large particles from the dispenser could also cause hygienic issues if they become soiled or cause slurry blockage as discussed in section **1.2.1**.

As reviewed in van de Weerd et al. (2009), many studies have shown that pigs' interactions with point-source items were typically lower compared to loose straw. However, most studies compared loose straw to inorganic hanging objects (Scott et al., 2006b; van de Weerd et al., 2003). The advantage of loose organic substrates when provided as bedding over when provided in fixed containers is less pronounced. Fraser et al. (1991) studied the provision of straw on finishers' (7 and 10 weeks of age) behaviours, and the provision of straw only caused a difference in behaviours (more active and less manipulation on any part of the body of pen mates) when provided as bedding and not in an elevated rack. Van de Weerd et al. (2006) compared four different types of enrichment (straw bed, straw rack, feed dispenser, liquid dispenser or hanging rubber chew toy) to undocked finishing pigs (starting from 55 kg). They found highest interactions with the enrichment in straw-bedded pigs, followed by the straw rack. No difference in pig manipulation (i.e. nosing or biting on tail, ear or hock) was found between any treatment, and in terms of tail biting outbreaks recorded, there was also no significant difference between pens with straw bed and the straw rack. In comparison, Lyons et al. (1995) did not find any difference in interactions between straw provided on the floor or via a dispenser. Similarly, Zwicker et al. (2013) also did not find differences in finishers' (from 30 kg) pen mate manipulation (including tail, ear, leg or belly) between different ways of providing loose materials (as litter, in a rack or from various types of dispensers), although interaction with the materials was always higher when provided as litter. Compressed straw blocks in a vertical dispenser have been shown to be less favoured by pigs in many studies either compared to other forms of loose materials or even plastic toys, due to limited accessibility and poor design of the dispenser (Bulens et al., 2015; Haigh et al., 2019; Zwicker et al., 2013), whereas a long elevated rack or trough can improve accessibility and increase pigs' use (Beattie et al., 2001; Bulens et al., 2015; Zwicker et al., 2012). Thus the method of providing loose materials as an alternative to bedding is crucial in affecting its use by pigs.

Previous studies demonstrated loose materials can still be as attractive and useful as bedding when provided by well-designed dispensers. However, as van de Weerd et al. (2006) also recorded, 50% of pens with straw rack had tail biting incidents, compared to 17% in straw bedded pens. Beattie et al. (2001) found spent mushroom compost supplied in a long-elevated rack per 18 finishers (35 – 95 kg) on fully-slatted floors (0·68 m^2/pig) reduced pigs' nosing behaviours in general (on fixtures, ground and other pigs) and the number of pigs with bitten tails (< 1% of pigs removed). However, Holling et al. (2017) failed to use a foraging tower (per 20 weaners and 10 finishers) supplied with chopped straw to further reduce tail biting among docked pigs on a fully-slatted commercial farm with a background of tail biting history. Similarly, Veit et al. (2016) reported a high percentage of tail loss in weaners provided with a floor bowl of either corn silage or alfalfa hay (with a pig to access ratio at 1.2:1 or 2.4:1), and no improvement from the control pigs which had no access to rooting materials. Whether it is possible to use a single loose material dispenser to control tail biting in a group of undocked pigs is still inconclusive.

1.2.4 Other non-particulate point-source items

When straw is unavailable, it may be possible to substitute it with other suitable alternatives under the condition that they can satisfy pigs' chewing and rooting needs (Fraser et al., 1991). When van de Weerd (2003) investigated pigs' preferences for different enrichment materials, including loose materials in fixed containers, some hanging items (rope, mop head, hessian sack and webbing) also invited sustained interest. Other studies have shown that a hanging rope was preferred over loose materials provided in a box (i.e. wood shavings or sawdust; Guy et al., 2013). Surprisingly, the chain, which is considered inappropriate enrichment in many studies (as reviewed by van de Weerd et al., 2009), was the one that was used more when paired with a box of sawdust. This suggests that when pigs are presented with paired items together, they may find different traits attractive in different things.

Unlike loose materials which can usually be spread over a large area in the enclosure, a major limitation for most point-source items is their accessibility. Therefore, it is hugely important to consider the presentation and location of point-source items. For example, rope is often favoured by pigs as previously stated, but sometimes knots were made on the rope to prolong its durability, and this reduced how much pigs interact with it since it became more difficult to chew on (Apple and Craig, 1992). Feddes and Fraser (1994) showed that pigs chewed more on a straight than a looped object, regardless of whether the material was made of cotton or soft rubber. Bulens et al. (2018) provided undocked finishers (30 – 110 kg, 11-12 pigs/pen) with a hanging toy, a compressed straw dispenser and a hiding wall, and found that these pigs had a higher frequency of tail biting but lower percentage of severe tail lesion scores compared to the control pigs with only a hanging toy. They concluded that the higher incidences of tail biting could be because the hiding wall reduced the lying space and caused more biting behaviour due to space competition. On the other hand, although objects provided on the floor can be movable and become more accessible to pigs, they are easily soiled and pigs' interest decreases quickly (Blackshaw et al., 1997; Bracke, 2007; Trickett et al., 2009). Besides the inherent properties of the enrichment such as edibility and destructibility, its presentation, location and design are all important factors to determine how effective it can be.

1.2.5 Multiple sources of enrichment items

Besides presentation and location, Guy et al. (2013) reported that by offering pigs two items together, the reduction of object interaction over time due to habituation may slow down, and the combination of items can also affect the level of interactions with each one. Trickett et al. (2009) also found an additive effect, i.e., the total time of interaction with both items equalled to the addition of time when they were presented alone, so the overall enrichment interaction was higher when a rope was presented alongside a wood post than with only a rope or a wood post. When Zwicker et al. (2012) provided different numbers of straw racks (1, 3, 6 or 8 racks per group) to finisher pigs (28 – 89 kg, in groups of 27 pigs), they found a linear increase in use with the number of racks present, and the competition for access to straw racks tended to be lower when more racks were provided. Straw is a material that is valued by pigs, therefore has a strong additive effect. Similarly, when finishing pigs (from 29 kg, in groups of 18 pigs) received four pine beams compared to only two beams as enrichment, the average interaction with enrichment was higher, the habituation with enrichment was slower, and a higher number of pigs per pen engaged with enrichment (Larsen et al., 2019). However, Scott et al. (2007b) did not find this additive effect when testing between one plastic hanging toy and four among finishers (from 12 weeks of age, in groups of 32 pigs and later reduced to 25 pigs). This implied it is the mixture of the quantity, quality and variety of the items that influence the additive effect, and not just the quantity alone.

However, there has been very limited research combining a variety of different enrichment materials with different properties. Telkänranta et al. (2014a) used a straw rack, a standard chain and wood shavings on the floor in addition to their enrichment treatments (fresh branch of birch, plastic pipe, branched chain, all of the above or no additional item as control) to groups of 11 undocked finishing pigs (from 8 weeks of age). The prevalence of tail and ear damage was lower in pens with all three items. However, the interaction with the shared items (i.e. the straw rack, standard chain and wood shavings) was not recorded, and therefore it was not possible to compare the overall interaction with all enrichment items. Still, by using a combination of different items, the overall prevalence of tail damage recorded was mild (46% of pigs with no damage recorded). Behavioural synchrony and social facilitation are common in pigs (Zwicker et al., 2015). It was observed in pens of six pigs, that when foraging materials were of high value (e.g. straw with maize or cut straw), there was a higher probability of behaviour synchrony taking place with more pigs (and the highest with all six pigs) actively foraging together than with fewer pigs (Zwicker et al., 2015). If a suitable quantity and quality of enrichment materials were absent in the pen, pigs tended to direct their attention to the pen fixtures, or towards other pigs. It is therefore essential to investigate further if the interaction with multiple enrichment items with different properties relevant to pigs can be more effective and longer lasting with a suitable enrichment to pig ratio.

Besides exploring the effect of different post-weaning enrichment on tail biting, the next section of this chapter now turns the focus towards how pre-weaning exposure to enrichment may affect pigs' behaviours later in life, especially by mitigating damaging behaviour such as tail biting. In the next section (**1.2.6**), the current knowledge on pre-weaning enrichment on pigs' later behaviour is reviewed.

1.2.6 Enrichment exposure during pre-weaning stage

A more complex or enriched farrowing system encouraged piglets' play behaviours during the pre-weaning period (Martin et al., 2015; Yang et al., 2018), however, its effect on damaging behaviours such as tail and ear biting was less clear (Prunier et al., 2019; Vanheukelom et al., 2012).

One difficulty in evaluating the effect of pre-weaning enrichment is that many studies incorporated both the pre-weaning (0 to 4 weeks of age) and the post-weaning periods (from 4 weeks of age onwards until 7 weeks of age) in the definition of early life environment (Day et al., 2002; Hötzel et al., 2004; Veit et al., 2016). This creates difficulty in assessing whether the effects detected later in life were solely attributable to pre-weaning experience. For example, Day et al. (2002) investigated the effect of prior experience with straw (crossover from pre-weaning to post-weaning until average weight of 27.2 kg), combined with different amount of straw provision in the growing and finishing stage. They found pigs which had prior experience with straw performed fewer other biting behaviours (excluding tail and ear biting) on their pen mates compared to pigs that had not been exposed to straw beforehand. Since the early experience with straw covered the period from birth until they reached 27.2 kg, it is not possible to distinguish how much effect can be attributed to their pre-weaning exposure to straw alone. Similarly, studies also showed that pigs enriched from birth until 8 weeks old displayed better immune response against infectious diseases compared to barren-housed pigs (Luo et al., 2017; van Dixhoorn et al., 2016).

Another issue is that the pre-weaning effect may only be transient immediately following weaning, and whether it can extend into the later stages of life is uncertain. Oostindjer et al. (2010) found pre-weaning enrichment only marginally increased feed intake within the first 48 hours post-weaning, compared to the strong positive effect of post-weaning enrichment on pigs' growth (Oostindjer et al., 2010). The authors only followed the pigs for two weeks post-weaning, and the long-term effect was unknown. Similarly, Brajon et al. (2017) found piglets enriched with straw in the farrowing pen performed fewer biting behaviours towards other pen mates on the day of weaning (3 weeks of age) but no difference later on Day 22 and Day 27, which showed the effect of pre-weaning treatment appeared transient.

Most studies found a stronger effect of post-weaning enrichment than pre-weaning. Van de Weerd et al. (2005) provided pigs with a rooting box, a liquid dispenser, straw bedding or nothing during either pre-weaning (0 to 4 weeks of age) or post-weaning (4 to 8 weeks of age). Pigs were housed in either straw-bedded or barren (with only rubber hanging toy available) pens from 10 weeks of age (i.e. the finisher stage). They did not find any difference in terms of skin lesions in the finisher stage (including body and tail lesions) due to any prior enrichment treatment, but when finishers were housed in the barren environment, the level of manipulation of other pigs (combining all nosing, chewing and biting on any part of the body) reduced only when they had had experience with any enrichment pre-weaning rather than post-weaning. No difference of early enrichment was found when the finishers' environment was enriched with straw, and less tail biting outbreaks were recorded in straw bedded than barren finishers, which suggested the impact of the current housing was still greater than their prior experience. Similarly, Oostindjer et al. (2011) reported that pigs housed in barren pens pre-weaning performed more pen-directed behaviours, play behaviours and were more active in general post-weaning, but their post-weaning housing had a stronger effect on almost all behaviours including pen mate directed behaviours.

In a more longitudinal study, Vanheukelom et al. (2011) provided pigs with a tray of peat pre-weaning or during the weaner stage (4-9 weeks of age), and followed the pigs from birth to slaughter. Pigs enriched before weaning slept less only if they were not enriched in the weaner stage, but in the finisher stage they became less active whether or not enriched in the weaner stage. However, with regard to performance, the results were more pronounced. Pre-weaning enrichment increased pigs' weight gain in the weaner stage, regardless of whether they were enriched during this stage, with the highest weight gain recorded when pigs had enrichment both pre-weaning and during the weaner stage. However, in the finisher stage, pre-weaning environment only had a positive effect on weight gain if pigs were enriched during the weaner stage. This study further showed that the pre-weaning treatment can have a stronger effect when combined with post-weaning treatment, but more in relation to growth than behaviours.

More specific to tail biting, Statham et al. (2011) investigated the timing of providing straw bedding on undocked pigs' tail biting behaviours. The pigs were either provided with straw throughout their life from birth (replenished twice/week), after weaning (25 ± 3 days), after moving to the finisher house (12 weeks of age), or with no straw at all. Pigs without access to straw received daily provision of wood shavings before moving to the finisher house. They did not find any difference in the occurrence of tail biting between treatments, and even in the straw 'throughout' groups, tail biting outbreaks were still recorded.

Telkänranta et al. (2014b) gave pre-weaned piglets 10 pieces of rope, full pages of newspapers twice a day, a hanging ball, and wood shavings as enrichment, compared with piglets which only had a ball and wood shavings. The pigs were housed in identical pens post-weaning (enriched with three ropes, a plastic chew toy and wood shavings provided twice daily) and followed for 5 weeks. A higher percentage of pigs with mild tail damage and a lower percentage of pigs with severe tail damage were found in pigs which had come from enriched pens prior to weaning. Likewise, Munsterhjelm et al. (2009) investigated the effect of enrichment provision (wood shavings and chopped straw, or no enrichment) during the pre-weaning stage (0-4 weeks of age), weaner stage (week 5-9) and finisher stage (week 10-24). Tail lesions in the weaner stage were worse when pigs did not have enrichment in the pre-weaning stage, and pre-weaning enrichment also decreased the frequency of all agonistic behaviours (including fighting, tail and ear biting) as late as at 14 weeks of age. Currently, these two studies were the only evidence that pre-weaning enrichment may play a part in pigs' damaging behaviour outcome later in life (Prunier et al., 2019).

Based on the current literature, it is still inconclusive as to how much the effect of pigs' pre-weaning exposure to enrichment will have on their tendency to perform damaging behaviours later in life, and especially how it interacts with post-weaning enrichment treatment. Moreover, in the context of fully-slatted systems, loose substrates cannot be used in the farrowing housing, where enrichment provision is limited to hanging items. Yang et al. (2018) showed that hanging toys and ropes could increase piglets' object play behaviour as much as substrates (wood bark in a box). It is worth investigating whether the utilisation of point-source items in the farrowing housing can have an effect on pigs' damaging behaviours and to what extent the effect will be evident later in life if combined with post-weaning enrichment exposure.

In addition to improved environmental enrichment, increasing dietary fibre also causes minimal disturbance to current farming practices and will be the focus of the next section (**1.3**).

1.3 Dietary fibre

Composition of the pigs' diet is also considered a risk factor for tail biting (D'Eath et al., 2014), however, the role of dietary fibre on damaging behaviours is better known in relation to feather pecking in laying hens (Van Krimpen et al., 2005). Poultry and pigs share similar motivation to forage and explore as they are omnivores, but in commercial rearing conditions, they are usually fed high concentrated feed with limited materials for them to forage (Brunberg et al., 2016).

This could increase the risk of feather pecking as well as tail biting. Studies have shown that providing laying hens with a diet high in insoluble fibre can reduce feather pecking (van Krimpen et al, 2005). In addition, insoluble fibre helped prolong feeding time and increase satiety in layers, which makes them calmer and reduced time spent foraging.

The impact of dietary fibre on growing pigs has mainly been studied in relation to pigs' digestive systems, feedstuff composition and production indicators (Jarrett and Ashworth, 2018; Lindberg, 2014). Provision of a high level of dietary fibre can slow down energy absorption in younger pigs but may also improve gut health (Jarrett 2018). Although studies on sows showed that high fibre diets can reduce their general activities, stereotypic and aggressive behaviours (Brooks, 2005; de Leeuw et al., 2008; Meunier-Salaun et al., 2001), they are usually restricted-fed during gestation, whilst most conventionally farmed grower-finishers are fed *ad libitum*. The age of the pig can also influence the effect of dietary fibre on their physiology and behaviour (Jarrett and Ashworth, 2018; Lindberg, 2014). When Bolhuis et al. (2010) studied the combined effect of provision of straw bedding with different levels of fermentability of fibre sources on growing pigs' behaviours when the pigs were restrictedly fed, similar results were found. It was suggested that high bulkiness in a fibre source can reduce oral manipulation immediately after a meal due to prolonged mastication during feeding, but it is the quality of high fermentability that can extend this effect to a longer duration (de Leeuw et al., 2008; Schrama and Bakker, 1999). Pigs fed with a highly fermentable fibre source spent longer time resting and shorter time exploring and moving (Bolhuis et al., 2010). They also displayed less aggression and manipulation of their pen mates, between the two feeding times. Interestingly, the authors found the effect was more pronounced when pigs had access to straw bedding, which suggested that the environment could have a stronger impact on pigs' behaviours when combined with dietary fibre.

Currently, Kallabis and Kaufmann (2012) is the only study looking at the effect of high fibre on behaviours of finishing pigs fed *ad libitum*. They compared pigs fed a standard fibre diet (5.18% crude fibre) with two different levels of higher fibre (7.33% and 8.39%) and followed them throughout the finisher stage. They reported that finishers fed with a higher level of dietary fibre usually had a reduced feeding rate and longer feeding bouts, but the effect was less clear when pigs reached over 80kg. This showed that high fibre increased pigs' satiety, decreased their motivation to feed and prolonged the feeding time, which is the same as what has been observed in restricted-fed sows. However, the authors did not record any other behaviour besides feeding, and therefore, it is uncertain if the general activity level or oral manipulation was reduced due to the change in feeding behaviours. Moreover, the protein and energy level of the treatment diets in this study was also slightly lower than the control diet due to the higher fibre content, and thus other impacts of the different diet compositions cannot be ruled out. As Bolhuis et al. (2010) suggested, whether foraging materials are available or not should also be considered when studying the effect of dietary fibre level, but Kallabis and Kaufmann (2012) only described the pigs as reared outdoors without mention of other features in their environment.

As the link between higher dietary fibre and less feather pecking was established in laying hens, and with the known effect of high fibre to generate a sense of satiety in pigs due to features such as bulkiness and water-holding ability, which increases the time required to masticate and improves the feeling of gut fill (de Leeuw et al., 2008), there is potential for high fibre diet to reduce tail biting which deserves further investigation.

1.4 Remedial methods for tail biting outbreaks

Despite all available methods to prevent tail biting, it is almost impossible to eliminate the occurrence of tail biting, due to the multiple risk factors involved and its sporadic nature. In herds with sufficient straw provision (Statham et al., 2011), outdoor or organic production (Alban et al., 2015; Hanne Kongsted and Sørensen, 2017; Rudolph et al., 2017), tail lesions were still recorded with different levels of tail loss observed. Especially when tail biting happens in the manner of outbreaks as described in section **1.1.1.2**, it can have severe consequences for pigs and farmers alike. Understanding how to intervene with tail biting outbreaks when it happens is essential and will have practical implications on farm.

Methods to halt tail biting outbreaks are frequently mentioned but usually from anecdotal observations and experiences. Schrøder-Petersen and Simonsen (2001) proposed three treatments of tail biting outbreaks based on the literature; 1) altering the social group of the pigs by removing biters, 2) using medical treatment of antibiotics or covering bitten tails with substances, and 3) surgically removing a part of the tail. Several surveys in Europe have reported farmers' practices to deal with tail biting outbreaks in different countries (Table 1.1). The most common practices were removing biters, removing victims and adding enrichment or bedding materials; most farmers chose to remove biters as the foremost important step. Nevertheless, the difficulty in identifying the biter pig(s) was expressed (Haigh and O'Driscoll, 2019; Hunter et al., 2001) and the variability of a pig's role in the event of tail biting has also been reported in experimental research (Ursinus et al., 2014a; Zonderland et al., 2011). Another issue that arises with the removal of pigs from the pen, either biters or victims, is the pressure of extra space requirement, since hospital facilities are usually limited on commercial farms (D'Eath et al., 2014; Valros et al., 2016). Little research discussing the removal of pigs has touched on the problem of subsequent management or rehoming of these pigs. It is well known that when adult pigs are mixed, aggression is a common issue and can sometimes lead to persistent fighting, severe body lesions and heightened stress level which impairs welfare and have consequences for performance (Marchant-Forde and Marchant-Forde, 2005; Turner et al., 2006). Zonderland et al., (2008) briefly mentioned that the mixing of removed biter pigs did not cause further tail biting among new groups, but with no mention of the aggression at mixing and measures taken to alleviate it.

Table 1.1. Surveys from different European countries on farmers' practices when coping with tail biting outbreaks in order of ranking as perceived importance

Country	Rank					Reference
	1	2	3	4	Other	
UK	Remove victims	Add enrichment	Remove biters	Use substance on bitten tails	Provide straw, reduce stocking density, use antibiotics	Hunter et al. 2001
Netherlands	Remove biters	Remove victims	Add enrichment	Improve climate	Clip teeth, grind teeth, use substance on bitten tails, dim light	Bracke et al. 2013
Sweden	Remove biters	Remove victims	Increase straw ration	Check ventilation /feeding	Add enrichment	Wallgren et al. 2016
Finland	Identify biters†	Remove biters	Add bedding	Remove victims	Add enrichment, reduce stocking density, use substance on bitten tails	Valros et al. 2016
Ireland	Remove victims	Add enrichment	Remove biters	Identify biters	Use substance on bitten tails, reduce stocking density, add bedding	Haigh and O'Driscoll , 2019

† In both the Finnish and Irish surveys, the farmers were asked to rank options to "identify biters" and "remove biters" independently.

It has been widely recognised that it is difficult to test intervention methods for tail biting outbreaks in a controlled experimental setting since outbreaks are difficult to induce or predict (D'Eath et al., 2014), and it is ethically unacceptable to compare with "no intervention" (Bracke, 2009; Edwards, 2011). To date, there have only been three experimental studies testing different strategies to intervene in tail biting outbreaks. Zonderland et al., (2008) conducted the first study. They followed weaners housed on partly slatted floors for five weeks, comparing two curative intervention measures. Tail biting outbreaks were defined as occurring when one pig with clearly visible fresh tail wound was identified, along with another pig with any type of tail damage (e.g. bite marks), out of a group of ten pigs, determined by close inspection and scoring of individual pigs' tails. The two methods tested were either providing long straw on the solid floor (20 g/pig/day) or removing one or two biter pigs. The criteria to evaluate the effectiveness of the intervention methods were the percentage of pigs within a pen having fresh blood on the tail scored daily for 10 successive days following the onset of an outbreak. The authors did not find differences in the percentage of pigs with fresh blood on the tails between the two methods, but both interventions did lower the percentage in the following days compared to Day 0 of the outbreak, although tail biting still persisted. This was reflected in the fluctuating percentage of tails with blood observed in the following days, although without further escalation to the point where more interventions were needed.

By using a rope as a proxy for tails, Bracke, (2009) examined the efficacy of Stockholm tar and Dippel's oil in curtailing pigs' rope manipulation. The application of either substance lowered the pigs' manipulation effectively, but as the author discussed, there may be a discrepancy between the rope test and actual tail biting outbreaks in terms of the nutritional feedback from pigs' tail compared to the synthetic rope. Moreover, although the author argued pigs are eager to chew a novel rope as much as they chew an actual tail, and the way a rope is destroyed gradually resembles the tissue breakdown of a tail, it is still questionable whether the motivation behind tail biting and therefore its subsequent development will be similar to rope manipulation, which is commonly used as a form of enrichment material. As mentioned in section **1.1.1**, tail biting is a behaviour which involves two subjects: the instigator (biter) and the receiver (victim). On the contrary, the rope manipulation only involves the instigator and an object, which does not provide interactive feedback. Nevertheless, this study has shown that the substance can induce some level of aversion in pigs and acts as a repellent to reduce manipulation.

More recently, Lahrmann et al., (2019) compared the effectiveness of stopping tail biting outbreaks by using one of three different types of enrichment provision: either a rope, a plastic hanging toy or a small amount of chopped straw (around 7 g/pig/day) provided on the floor. Outbreaks were defined when four out of 30 pigs in a pen had any tail wounds more severe than superficial scratches during tail scoring inside the pens. After an intervention was allocated, if four or more fresh wounds were recorded, or any biter pig needed to be removed due to a severe wound, the intervention was considered unsuccessful. Results showed that all interventions reduced tail-directed behaviours although there was a slight increase on Day 7 compared to Day 0 and Day 2 when using ropes and toys, and thus the provision of straw seemed to be more effective than the rope and toy in curbing an escalation of tail biting. Nevertheless, the authors also reported that even with straw, there was still a probability of 25% of tail biting escalating, and thus other steps are needed to consistently halt tail biting outbreaks. However, the authors did demonstrate a way of using a predefined threshold to evaluate when an intervention can be considered unsuccessful. As discussed in section **1.1.4.1**, the evaluation of outbreak remedies largely depends on the definition of an outbreak itself and its termination. The criteria used in this study were extremely low, and considered an outbreak to have commenced when tail damage was mild and detectible during individual tail inspection. This is likely going to be impractical on a commercial farm. Therefore, when a tail biting outbreak is identified at a more progressed stage, it is uncertain whether the same strategies will render similar outcomes. However, it still showed the importance of early intervention in tail biting and the potential of additional enrichment to stop tail biting during its earlier stage of development.

Current knowledge on how to intervene in the case of tail biting outbreaks is lacking, and the few experimental studies in the literature employed outbreak definitions that may not be applicable on farm. Moreover, outside experimental settings, farmers need to exert all remedial measures when tail biting outbreak occurs, and due to its complex nature, sometimes a combination of different intervention methods may be required. It is therefore crucial to have a clear definition of tail biting outbreak, and to design a more progressive intervention strategy in order to provide practical advice for farmers when encountering tail biting outbreaks.

1.5 Economic impact of tail biting, enrichment and not docking pigs' tails

It is recognised that there can be substantial economic loss due to severe tail biting from extra labour and hospital pens, medical costs, premature mortality and carcass condemnation (D'Eath et al., 2016; Valros, 2018). However, Valros et al. (2015) suggested that the overall cost of tail docking including labour, welfare compromise, and subsequent negative effects on pig's health and growth is usually underestimated. Harley et al. (2014) showed that with routine tail docking but without improvement in on-farm rearing conditions, the economic loss from lighter carcass weight due to tail biting was still €0.59 per pig. To encourage farmers to stop tail docking, the economic consequences of tail biting, tail docking and enrichment provision should all be considered. In Finland, where tail docking is always illegal, a survey showed that over 70% of farmers did not consider tail biting a major problem, and more than 60% of farmers would not practice tail docking even if it were legal (Valros et al., 2016). When plentiful variation of enrichment was present, including provision of chopped straw, undocked pigs housed on partly-slatted floors did not display more tail manipulating behaviours (Paoli et al., 2016).

Currently, the urgent question is whether undocked pigs can maintain a low level of tail biting in a fully-slatted system where fewer enrichment options are available.

According to economic modelling of different partly-slatted housing scenarios, which incorporated tail docking or not, different slat area ratios, stocking densities, and enrichment provision on financial outcome, none of the non-docking scenarios modelled generated economic incentive compared to docking (D'Eath et al., 2016). The difference may be even greater if compared to fully-slatted housing. However, the known benefit on pig performance from better enrichment provision (Averós et al., 2010; van de Weerd and Day, 2009) is rarely considered, and the possible effect on performance with undocked pigs also needs to be investigated. Furthermore, if infringement on routine tail docking is enforced, the economic incentive may be enhanced. Therefore, it is important to find solutions that could be feasible to be applied in the current system while taking into consideration the cost of the solutions proposed during evaluation.

1.6 Conclusions

Having considered the current literature on the urgency in tackling the issue of tail biting, the existing preventative methods and the limits of the housing systems in question, this PhD thesis aims to contribute in finding practical strategies to manage pigs without docking their tails, in fully-slatted systems. As improvements in the provision of environmental enrichment and alteration of dietary fibre cause the least disruption to this type of production system, they are the main focuses of this thesis. In terms of enrichment, the most suitable options to use on fully-slatted floors still require further investigation. Wood has an advantage as an economically feasible material, but the properties of different wood species as environmental enrichment for pigs have not yet been investigated. Similarly, the potential benefit that dietary fibre may have on minimising tail biting is also unknown. Moreover, it is uncertain whether it is possible to keep tail biting at a manageable level without detrimental impact on pig welfare and production loss in undocked pigs using enrichment provision that is compatible to the fully-slatted system, either by early exposure to enrichment or by providing a good quality, quantity and variety of enrichment items simultaneously. Finally, besides investigating methods to mitigate the occurrence of tail biting, this thesis also examines strategies to intervene when severe tail biting outbreaks take place.

Chapter 2 Overview of the thesis

This PhD thesis takes a practical approach at aiming to find solutions for pig producers to rear undocked pigs on fully-slatted floors. The main focus is on investigating suitable environmental enrichment materials, with a minor part on dietary fibre.

The main objectives of the thesis are to:

1) Identify whether different wood species affect the amount and type of pigs' interaction with a long block of wood, presented in a pen-side holder, and based upon the results, determine which species of wood would be most suitable for use as an enrichment material
2) Investigate whether wood is more effective than a rubber floor toy as enrichment for pigs in terms of attracting higher interaction and reducing damaging behaviours
3) Identify commercially feasible strategies to manage tail biting in undocked pigs on fully-slatted floors, focusing on the role of dietary fibre and more enhanced enrichment provision due to practicality to be applied in the current housing system on Irish commercial farms (fully-slatted floors)
4) Test a range of practical intervention strategies which aim to stop severe tail biting outbreaks

The experimental studies conducted during the course of the PhD followed a progressive development, starting with using docked, finisher pigs, to test one enrichment item at a time (**Chapter 3 and 4**), followed by rearing undocked from weaning to slaughter at two different dietary fibre levels (standard or high), with a single favourable enrichment item, identified in the preceding studies (**Chapter 5**). The choice of testing dietary fibre and a single enrichment was based on the consideration that this would be more in line with current commercial practice on Irish pig farms, with the least disruption to the existing housing system and negative economic impact. Finally, undocked pigs were reared from birth to slaughter using multiple enrichment items per pen (eight items per 12 pigs), and with variation in the rate of replenishment (**Chapter 6**). The experimental studies are listed as follows:

Study 1 (**Chapter 3**) – Use of different wood types as environmental enrichment to manage tail biting in docked pigs in a commercial fully-slatted system

- Hypothesis: different wood types will contribute to different frequencies of interaction from pigs and of damaging behaviours

Study 2 (**Chapter 4**) – Enrichment use in finishing pigs and its relationship with damaging behaviours: comparing three wood species and a rubber floor toy

- Hypotheses: wooden enrichment will generate higher, longer bouts and more even distributions of interaction and a lower amount of damaging behaviours than the rubber toy

Study 3 (**Chapter 5 / 7**) – Can increased dietary fibre level and a single enrichment device reduce the risk of tail biting in undocked pigs on fully slatted systems?

- Hypotheses: high dietary fibre and spruce as enrichment will reduce the risk of tail biting

Study 4 (**Chapter 6 / 7**) – A high enrichment replenishment rate reduces damaging behaviours and increases growth rate in undocked pigs kept in fully-slatted pens

- Hypothesis: early exposure to enrichment pre-weaning combined with a high enrichment replenishment rate will reduce damaging behaviours and be economically beneficial

Chapter 7 – Multi-Step Tail Biting Outbreak Intervention Protocols for Pigs Housed on Slatted Floors

- Hypothesis: the intervention protocols will lead to different success rate and duration in overcoming tail biting outbreaks

The investigation began with a review of literature relevant to the subject matter (**Chapter 1**). Due to the large amount of literature dedicated to tail biting, enrichment and tail docking, only literature most relevant to the thesis subject was included in the review. The current chapter (**Chapter 2**) provides an overview of the objectives and structure of the thesis. Except for **Chapter 6**, all other experimental chapters are presented in the format of scientific papers, either already published or submitted as manuscripts for publication. Additional introductions and discussions are provided with each chapter to link them, and show how the PhD progressed. Contributions by the authors are clearly indicated. At the end of the thesis a general discussion is given to integrate and discuss the different findings in all studies (**Chapter 8**).

Chapter 3 Use of different wood types as environmental enrichment to manage tail biting in docked pigs in a commercial fully-slatted system

This chapter is the published paper in *Livestock Science* on 6 Apr 2018: Chou J.-Y., D'Eath RB, Sandercock DA, Waran N, Haigh A and O'Driscoll K. 2018. Use of different wood types as environmental enrichment to manage tail biting in docked pigs in a commercial fully-slatted system. *Livestock Science* 213, 19–27. https://doi.org/10.1016/j.livsci.2018.04.004 Due to copyright issues, the accepted manuscript is attached here.

This chapter had been previously presented as a poster in: **Chou, J.-Y.**, Haigh, A., D'Eath, R., Sandercock, D., Waran, N. and O'Driscoll, K. 2017. Use of different wood types as enrichment to reduce tail biting in pigs managed on fully-slatted floors. Proceedings of the UFAW International Animal Welfare Science Symposium, 27-29 June, London, United Kingdom.

Introduction to Chapter 3

This chapter consists of the first study conducted during the PhD studentship, as part of a larger project on enrichment and tail biting funded by Department of Agriculture, Food and the Marine in the Republic of Ireland. As part of that project a survey was initially carried out with Irish pig producers (Haigh and O'Driscoll, 2019). This found that wood is a material that was very favourable to producers for use as environmental enrichment. Therefore, as a starting point of the PhD inquiry, the primary aim of this study was to identify whether different species of wood perform differently in terms of attracting pigs' interaction, and other measures such as lesion scores and damaging behaviours. The study was conducted on a commercial farm in order to collect data which is applicable to an applied setting. I contributed to the experimental design, data collection, statistical analysis, data presentation, original draft preparation and review and editing of the final publication. During data collection, help was provided by Teagasc technician David Clarke, and intern students Madeleine Munkonka and Fiona Dunne. Among the co-authors, Natalie Waran was my university supervisor from Oct 2015 to July 2016. Amy Haigh was a post-doctoral researcher who worked under the main project incorporating this PhD thesis. She has participated in experimental design, data collection, co-supervision and the review and editing of the publication.

This study was part of a larger study approved by the Teagasc Animal Ethics Committee (TAEC89/2015). As required in the ethical approval application, sample size was estimated using the GLMPOWER procedure in SAS v9.3. Based on previous studies compared the prevalence of tail lesion with different enrichment provisions (Goossens et al. 2008, Petersen et al. 2008 , Smulders et al. 2008), a difference of 0.9 with an estimated standard deviation of 0.5, a significance level of $p < 0.05$, and a power value of 0.8 were used.

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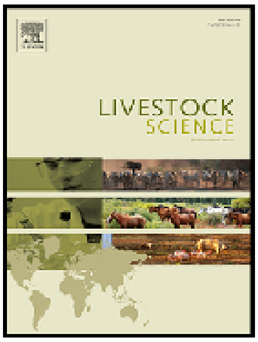

Use of different wood types as environmental enrichment to manage tail biting in docked pigs in a commercial fully-slatted system

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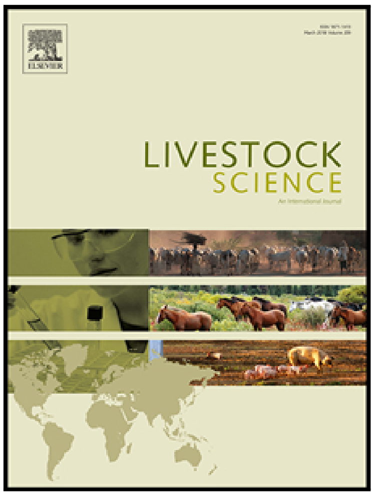

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Highlights

- Spruce was consumed more quickly than other wood types.
- Pigs interacted with spruce more frequently than other wood types.
- No time effect was found on wood use.
- Replacement rate rather than cost may be a practical concern.

Use of different wood types as environmental enrichment to manage tail biting in docked pigs in a commercial fully-slatted system

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Abstract

Provision of adequate environmental enrichment on pig farms is a legal requirement under current EU legislation and also alleviates the risk of tail biting. Wood is an organic alternative where loose bedding, which has been identified as the optimal enrichment, is not possible on fully-slatted floors since it may disrupt the slurry system.

The study compared four different wood types (beech (*Fagus sylvatica*), larch (*Larix decidua*), spruce (*Picea sitchensis*), and Scots pine (*Pinus sylvestris L.*)) as enrichment, taking into account the qualities of the wood, economic considerations, and effectiveness at reducing damaging behaviours and lesions. A total of 800 tail docked finisher pigs on an Irish commercial farm were used. Eight pens were provided with each wood type (25 pigs/pen), and the study was conducted over 2 replicates in time. In each pen a single wooden post was presented to the pigs in a metal dispenser with two lateral chains during the finisher period (12 to 22 weeks of age). The rate of wear, moisture content, and hardness of the wood along with lesion scorings and behavioural observation on pigs were monitored. Spruce was consumed more quickly than other wood types in terms of weight loss and reduction in length ($P<0.001$), resulting in a greater cost per pig. Pigs were observed interacting with the spruce more frequently than the other wood types ($P<0.05$). Pigs also interacted with the wood more often than the chains in spruce allocated pens ($P<0.001$). Overall the interaction with wood posts did not decline significantly across time. However, there was no difference in the frequency of harmful behaviours (tail/ear/flank-biting) observed between wood types, and also no difference in the effectiveness of the different types of wood in reducing tail or ear damage. There was a positive correlation between ear lesion and tear-staining scores ($r_p=0.286$, $P<0.01$), and between tail lesion and tail posture scores ($r_p=0.206$, $P<0.05$). Wood types did not affect visceral condemnation obtained in the slaughterhouse. Wood is a potentially suitable enrichment material, yet the wood species could influence its attractiveness to pigs.

Keywords

Finishing pigs; harmful behaviours; wood posts.

1. Introduction

Tail biting is one of the most serious issues in pig farming. It negatively affects both pigs and farmers, causing injuries and distress to the former and economic loss to the latter (Harley et al., 2014). The causes of tail biting are multifactorial, and involve numerous risk factors. These range from internal factors such as genetics, gender, age, and health of the pig, to external factors, including ventilation, feeding, stocking density, and environmental enrichment (Schrøder-Petersen and Simonsen, 2001; Zonderland, 2010; D'Eath et al., 2014). This makes tail biting especially difficult to prevent and control. Despite an EU Council Directive stating that routine tail docking is banned as a preventive measure to control tail biting (Council Directive 2008/120/EC), tail docking is still commonly used for this purpose, with some countries having almost 100% of pigs docked (Harley et al., 2012; D'Eath et al., 2016). However, tail docking does not eliminate tail biting. In Ireland, even though 99% of pigs are tail docked, over 25% of pigs still have identifiable tail-lesions during carcass inspection (Harley et al., 2014).

Inadequate environmental enrichment has been identified as a major risk factor for tail biting (EFSA, 2007). Provision of loose straw is generally considered the gold standard in successfully reducing, even if not completely eliminating, tail biting (Schrøder-Petersen and Simonsen, 2001; Van de Weerd et al., 2006; Studnitz et al., 2007; Scollo et al., 2013), but it needs continuous replenishment which increases production costs and labour. Moreover, on fully-slatted floors loose straw can obstruct faeces from going through the slats, or block the drainage system (D'Eath et al., 2014). These issues create a "systemic inertia" against use of loose straw amongst farmers who use the slatted systems (D'Eath, 2015). Therefore, economically feasible materials appropriate for slatted systems and capable of satisfying pigs' behavioural needs (Studnitz et al., 2007; Van de Weerd and Day, 2009) need to be identified.

In March 2016, the European Commission issued a recommendation regarding management of tail biting in pigs, reiterating that enrichment materials should be edible, chewable, investigable, and manipulable (European Commission, 2016a). Wood was categorised as a suboptimal enrichment, yet appropriate for use in fully-slatted systems where loose bedding cannot be provided (European Commission, 2016b). A recent survey of farmer attitudes to enrichment and tail biting in Ireland found that wood was frequently used, or that they would consider using it in the future (Haigh and O'Driscoll, 2016). Effectiveness and longevity were the two strongest factors influencing their decision making, followed by cost. These two criteria may appear to be paradoxical as more effective enrichment materials are usually more destructible and less durable (Van de Weerd et al., 2003). Examination of these features is one of the areas of focus for the current study.

Canning et al. (2013) have compared two methods of wood provision in pigs, and found that as a rooting device, when the wood was positioned touching the ground, it was less frequently used than a hanging lever device, due to soiling of the wood. Both hard and soft woods were used in that study, but the specific wood species were not reported. Telkänranta et al. (2014) compared wood (a hanging fresh branch of birch *Betula pendula* and *Betula pubescens*) with chains, and polythene pipe. When all enrichment types were present, pigs tended to interact with branches more. Moreover, although time spent performing harmful behaviours did not decrease, where wood was present pigs sustained less ear and tail damage. However, pigs in this study were housed on partly-slatted floors and all pens were also equipped with a straw rack, a metal chain and wood shavings. Thus the results may have been different if only wood was used.

Research comparing different wood types as enrichment has been mostly conducted on small animals. Ditewig et al. (2014) reported that enrichment type did not influence rat physiology when provided with an aspen (*Populus*) wood block. However, softwoods can contain aromatic hydrocarbons that may be toxic after long term consumption, and can damage liver function of rodents and rabbits (Froberg-Fejko, 2012). It is not known if there could be a similar effect on visceral deterioration in pigs after using wood, although no other detrimental effect of wood type enrichment on the carcass has been reported in meat rabbits (Jordan and Štuhec, 2002; Kermauner et al, 2004; Jordan et al., 2008). Moreover, to date no research has been undertaken to directly compare different wood types on the effectiveness of reducing tail biting in pigs in a fully-slatted floor system for pigs.

The objective of this study was to investigate whether different wood types would vary in their durability and effectiveness as environmental enrichment materials in terms of reducing pigs' harmful behaviours and lesions, and also to determine whether the provision of wood had any detrimental effects on pig health and performance that would potentially prevent the uptake of this enrichment by farmers. We hypothesised that different wood types would have different durability and effectiveness in reducing harmful behaviours and severity of lesions, and that wood would be a suitable enrichment material to use without any negative impact on pig health and performance.

2. Materials and methods

2.1 Animals, study design and housing

The experiment was conducted on an Irish commercial farm with a herd size of 2000 crossbred (Large White x Landrace) sows in Co. Cork, Ireland, and the disruption of the usual farm practices were minimised while carrying out the experiment. A total of 800 short-docked pigs (with an approximate length of 5cm when entering the finisher house), housed in 32 mixed-sex groups of 25 pigs, were followed in this study from entering the finisher stage (about 12 weeks of age; 42.71±1.17 kg) for 9-10 weeks until slaughter (21-22 weeks of age). The experiment was replicated over time, with 400 pigs included in each replicate. The sexes of pigs were randomly mixed in each pen, and the males were not castrated. In the weaner stage the pigs were given rubber hanging toys and in the grower stage one round Scots pine (*Pinus sylvestris L.*) wooden post. Traditional Trowbridge-style finishing pens were used in the experiment. These were stable-like pens with one side open to the outside through automatically thermal-controlled flip-up covers, all in the same row facing the same direction. The pens measured 6.2 m × 2.4 m, with a common feeding trough across the pen on one side of the wall (25 cm feeder space per pig), and a fully-slatted concrete floor. The feed provided was home-milled, standard commercial finisher diet, delivered four times per day. The pigs had access to a water drinker, natural ventilation and natural light.

At the time of movement to the finisher house, pigs were weighed and divided into groups of 25 (i.e. 16 groups of 25 pigs per replicate). Each group was then assigned by weight to one of four blocks. Within each block, one group was randomly assigned to each of the following 4 wood types from the start of the finisher stage until slaughter: one squared beech (*Fagus sylvatica*) wooden post (average starting length 1.217m, weight 2.205kg, circumference 0.200m), one squared larch (*Larix decidua*) wooden post (average starting length 1.219m, weight 2.48kg, circumference 0.228m), one squared spruce (*Picea sitchensis*) wooden post (average starting length 1.098m, weight 1.06kg, circumference 0.194m), and one round Scots pine (*Pinus sylvestris L.*) wooden post (average starting length 1.129m, weight 2.07kg, circumference 0.233m). Bark was removed from all the posts. The Scots pine was already in use on the farm and was supplied by the dispenser manufacturer (Jetwash Ltd., Ireland); the other three types of wood were bought in from sawmills, were untreated, and were of similar size within each wood type. Wood species were chosen for their different hardness and moisture levels based on a pilot study. Each wood type was used in 4 pens per replicate and thus 8 pens in total. As under current EU legislation (Council Directive 2008/120/EC) provision of environmental enrichment is mandatory, for ethical and legal reasons no negative control (no enrichment) treatment was applied.

For all wood types, the wooden posts were provided to the pigs using a commercially-available metal dispenser (Jetwash Ltd., Ireland). The dispensers consisted of a vertical metal cylinder (H 0.30 m × 0.08 m in diameter) which was attached to the wall opposite to the feeder trough, into which wooden posts were inserted (Figure 1). The wood drops through the metal cylinder, and is supported by a metal plate 0.2m below the bottom end of the cylinder, leaving the wood post exposed for access by the pigs between the bottom of the metal cylinder, and the supporting plate underneath it. Chains were attached to either side of the bottom of the cylinder, hanging next to the exposed wood to attract pigs' attention. The dispensers were installed so that the lowest part (the metal plate) was 0.2m above the surface of the pen floor.

The Scots Pine was provided to the farm for free by the dispenser manufacturer, but the unit price for subsequent purchasing was obtained. The other 3 types of wood posts selected were purchased based on price per wood post. Due to variation in the starting weight between posts, the cost was calculated using the average starting weight and calculating price per kg. The cost for

Scots pine, beech, larch, and spruce was 170, 167.35, 157.42, and 171.31 Euro cents per kg respectively.

2.2 Wood measurements

Prior to the start of the experiment and subsequently each week the following measures were taken on the wooden posts: weight (kg), length (m), circumference (m, taken at 0, 0.1, and 0.2m from the bottom of the post where it was exposed for pigs' use), hardness (shore D scale, measured using a durometer AD-300, Checkline Europe, and three randomly determined readings taken at 0, 0.1, 0.2, and 0.4m from the bottom of the post), and moisture level (%, using Hydromette BL-H-40, Gann, Germany, taken at 0, 0.1, 0.2, and 0.4m from the bottom of the post). The moisture meter employed two probes manually hammered into the wood post. Thus only one reading was taken to maintain the integrity of the post and reduce the risk of weakness or damage from excessive hammering. The moisture reading was automatically adjusted by the device to take account of the local temperature. In a situation where knots in the wood were exposed and needed to be removed manually these were weighed, and the date recorded. The wooden posts were replaced whenever the cylinder was emptied so that there was always wood available to the pigs.

2.3 Animal-based measures

Direct behaviour observations were carried out by 2 observers on a fortnightly basis starting from a week after the trial began. Inter-observer reliability was tested using Pearson's correlation (r_p=0.849, P<0.001). Two sessions of observations of each pen were carried out (at 11am and 3pm to avoid clashing with feeding), and each session last for 3 minutes (total of 6 minutes/pen/day). The ethogram was adapted from van Staaveren et al., 2015 (Table 1), and focused on harmful, social and play behaviours, as well as interaction with the enrichment device. Interaction with the enrichment device was recorded as either interaction with the wooden post or the metal dispenser (i.e. the cylinder and the chains). Before the observations began, the flaps at the entrance to the pens were opened, and the observer walked along the external corridor, habituating the pigs to human presence and waiting for the pigs to resume normal activities (no longer than five minutes). The observer then stood immediately outside the door to each pen to perform the observation. Due to the layout of the Trowbridge housing, the observer needed to keep a close proximity to the pen to be able to observe the whole pen. The observation only started once the pigs had ceased startling reactions and resumed normal behaviours to keep the observer effect to a minimum. The frequency of behaviours was manually recorded.

Tail and ear lesions, and tear staining were scored individually at the time of assignment to treatment, and on a fortnightly basis thereafter. Recordings were taken from pigs inside the home pen. Due to safety concerns, the last lesion scoring was in week 6 (when pigs were 18 weeks of age). Tail lesions were scored using the system adapted from Hunter et al. (1999; Table 2). In addition, the posture of each tail was recorded at the moment of tail lesion scoring (0: upward, 1: between up and down including sticking straight out, 2: Down pointing towards body; from Zonderland et al., 2009). Scoring for ear lesions was based on the system published by Telkänranta et al. (2014) and a pictorial guide (Table 3) developed by Diana et al. (in prep). Tear staining scoring was carried out using the DeBoer-Marchant-Forde Scale (Score 0-5; DeBoer et al., 2015). Again, due to constraints of scoring pigs in the home pen with regard to the recorder's safety and the subject's head orientation and visibility, only one eye (whichever was easier to view) was scored for each pig following the DeBoer et al. (2015) scoring system.

2.4 Production performance and carcass data

Pigs were weighed as a group at the start of the trial, and they were tattooed for group identification before being sent to the slaughterhouse. The cold carcass weight of each pig was recorded at the slaughterhouse. The tail damage on each carcass was inspected by a single observer on the processing line using the carcass tail lesion scoring system of Harley et al. (2012). Carcass and visceral condemnations, especially digestive and liver damage that might relate to wood use, were recorded on the slaughter line following the instructions from the veterinary inspectors on site.

2.5 Statistical analysis

Statistical Analyses System (SAS, version 9.1.3, 1989, SAS Institute Inc., Cary, NC) was utilised to analyse the data. Data were initially screened for outliers by using the univariate procedure. Residuals were checked for normal distribution, and only the loss of length needed to be transformed using log10 before analyses. Tukey-Kramer adjustments were used to examine differences between least square means.

Wood data were analysed using Linear Mixed Models (LMMs), including the fixed effects of treatment, time (week 0 to 10) and replicate, and the random effect of pen. The position where readings of circumference, moisture and hardness of the wood post were taken was also considered as a fixed effect. The cost comparison was based on weight loss (kg/week) multiplied by the unit price of each type of wood, and the average of 10 week in the finisher stage was used to estimate the cost per pig.

Behavioural data were analysed as frequencies per minute. Interaction with the enrichment was further broken down into percentage of interaction with the wooden post or the metal dispenser, and differences in the frequency of interaction between the two were also analysed. LMMs were used to analyse the data, using the fixed effects of treatment, time (week 1, 3, 5, 7, 8) and replicate, and the random effect of pen was also included. The interaction between treatment and time was also considered.

All lesion scores were recorded individually for each pig but analysed as both a percentage in group and a group mean as no individual identification was available. LMMs were used, including the fixed effects of treatment, time (week 0, 2, 4, 6) and replicate, and the random effect of pen. Pearson's correlation was used to investigate associations between different lesion scores, and these were analysed at the pen level. Production performance were analysed by initial weight and cold carcass weight, also using LMM, including the fixed effects of treatment and replicate, and the random effect of pen.

3. Results

3.1 Wood measures

There was a difference between types of wood in the rate of decrease in weight ($F_{(3, 22.6)}$=8.79, P<0.001) and length ($F_{(3, 27.9)}$=17.8, P<0.001). Spruce showed the greatest reduction in both weight and length compared to the other three species, which were not significantly different from each other; however, beech was numerically the most durable (Figures 2 and 3). Hardness also differed significantly between wood types ($F_{(3,36.8)}$=34.03, P<0.001). Post-hoc testing showed that beech was harder than all other types of wood (P<0.05), larch was harder than spruce and Scots pine (P<0.001), while spruce and Scots pine did not differ from each other (Figure 4). Finally, Scots pine had a higher moisture level than spruce and larch ($F_{(3,28)}$=8.47, P<0.001; Figure 5).

In terms of circumference, there was an effect of both wood type and position on the wood post. Similar to weight and length, the change in circumference was greater in spruce (0.071±0.009m) than in larch (0.013±0.013m) and beech (0.006±0.014m) ($F_{(3, 33)}$=7.67, P<0.001). At the highest measuring point (0.2m from the bottom of the wood post) the change was the smallest (0.022±0.006m; $F_{(2,908)}$=15.77, P<0.001) compared to at 0m (0.030±0.006m) and 0.1m (0.034±0.006m). There was no effect of time (weeks of the experiment) on the rate of weight loss, length reduction or change in circumference.

Cost difference was calculated based on kg of wood loss per week. Across the wood types, the difference in cost (€) per week was significant; spruce was higher (€0.46/week) than Scots pine (€0.12/week), beech (€0.10/week) and larch (€0.14/week) ($F_{(3,19.2)}$=9.19, $P<0.001$). When the cost per pig during the entire finisher stage (10 weeks) was compared, spruce, Scots pine, larch, and beech cost €0.18/pig, €0.04/pig, €0.04/pig and €0.02/pig respectively. On the farm where the experiment took place, the enrichment was reused between batches, but if the value of the remaining posts was taken into account (i.e. the posts were discarded after each batch), there was no difference in terms of cost between wood types during the experiment.

3.2 Behavioural assessment

There was no difference between wood types in the frequency of interaction with the entire device (wood post and the metal dispenser; Table 4). However, when considering only the wood, more interaction occurred with spruce than beech ($F_{(3, 81.2)}$=3.46, $P<0.05$; Figure 6). Moreover, the proportion of interaction with wood relative to those with the entire enrichment device was also higher in the spruce pens (45.63%) than in beech pens (28.34%) ($F_{(3, 85.7)}$=4.03, $P<0.01$). By contrast, there were more interactions with the metal dispenser than the wood post when given beech ($P<0.001$) and larch ($P<0.01$), while in Scots pine and spruce pens no difference was found.

There was no difference in the frequency of tail biting, ear biting or other harmful behaviours between wood types, nor was there a difference when all damaging behaviours were combined (Table 4).

There was an effect of time on some of the behaviours observed (Table 5). Overall activity level (i.e. the sum of all frequencies of all behaviours) was the lowest in week 8 ($P<0.001$). The highest frequency of tail biting was observed in week 5 ($P<0.001$), and ear biting in week 7 ($P<0.001$); similarly, in week 7 there was a peak in the frequency of all harmful behaviours combined (tail + ear + flank biting + belly nosing, $P<0.001$). The interaction with the entire enrichment device was significantly lower in week 8 ($P<0.001$) than week 1, 3, and 5, and the interaction with chains and metal dispenser was the lowest in week 8 ($P<0.001$; Table 5), but there was no difference in the interaction with the wood post across time considering all wood types (Figure 7).

3.3 Lesions and tear staining scorings

There was no effect of treatment on lesion scores, but the mean tail lesion scores were lower than 1 which represented mild scratches, and ear lesions recorded were mostly superficial scratches during the experiment (Table 6).

There was an effect of time on both lesion and tear staining scores. Tail lesion scores were the lowest in week 1 ($P<0.001$), and tear staining score also increased across time with the lowest score in week 0 and highest in week 6 ($P<0.001$; Table 6). The highest ear lesion scores occurred in week 0 and week 6 of the study ($P<0.05$).

A positive but weak correlation was found between pen-based ear lesion and tear-staining scores ($r_p=0.286$, $P<0.01$), and tail lesion and tear-staining scores (r_p=0.076, P<0.001). Similarly there was a positive but weak correlation between tail lesion and tail posture scores (r_p=0.206, P<0.05).

3.4 Production performance and carcass data

The average pig weight at 12 weeks of age (at the start of the experiment) was the same across wood types (Scots pine 43.4±1.14kg, spruce 42.45±1.14kg, larch 42.65±1.14kg, beech 42.35±1.14kg). There was no significant difference in the recorded cold carcass weight between wood types, and no visceral condemnation was found at slaughter that could be attributed to wood consumption. Tail lesions scored on the carcass corresponded with the tail lesions scored alive, where pigs in rep 2 (0.99±0.05) had worse tail lesions than rep 1 (0.72±0.05; $F_{(1, 26.1)}$=13.94, P<0.001).

4. Discussion

The aim of this study was to investigate whether different types of wood used as environmental enrichment would perform differently in terms of durability, attraction to the pigs, and effectiveness in control of tail biting. To this aim, we selected wood types with varying degrees of hardness and moisture levels to better understand how these traits would affect their performance as an enrichment material. Spruce, which was softer, was used up more quickly than the other three, likely because it was more easily degradable by oral manipulation. Moreover, the overall frequency of interactions as well as the proportion of interactions with the wood post compared with the metal device was the highest in the spruce pens. This suggests that pigs preferred the softer wood posts to the metal dispenser while at the device. Indeed studies on different enrichment materials have shown that being destructible contributes to higher interaction from the pigs (Van de Weerd et al., 2003; Studnitz et al., 2007; Van de Weerd and Day, 2009).

Scots pine and beech had the highest moisture levels, suggesting that although spruce was the softest and most easily degradable, this was likely not to be related to its moisture content. Beattie et al. (1998) compared different types of substrates and used preference testing to understand which material pigs preferred. They concluded the texture had a greater influence on pigs' preference than moisture. This ties in with our results as there was no obvious relationship between moisture level and the frequency of use or rate of wear. A lower moisture content of spruce could provide a benefit in terms of preservation and long term storage. The high moisture content of the Scots pine may explain the smaller margin in weight loss even though it had the same level of hardness as spruce. It could also be due to the presence of knots, which were only observed in this wood type.

The weight loss, length reduction or change in the circumference of the wood posts was not different between weeks. This constant wear suggests that all wood types sustained ongoing interest from the pigs, which was also supported by the behavioural data. In contrast, the frequency of interaction with the metal dispenser and chains was significantly lower at later stages of the experiment. Previous studies have shown that the qualities of enrichment being edible and destructible contributed to a sustained interest from pigs (Van de Weerd et al., 2003). Although compared to loose bedding such as straw, the quantity used and replenish rate of the wooden posts was lower (D'Eath et al., 2016), they possess these qualities whereas the metal part of the device does not. This could explain why the posts attracted the pigs' attention for the duration of the experiment. Nevertheless, the study demonstrated that different wood types have different levels of these qualities, a consideration which is important to take into account when supplying enrichment.

Trickett et al. (2009) used loose wood blocks placed on the floor and found no effect of time on the interaction, but it was always lower with the wood block than with rope, or treatments combining and alternating rope and wood blocks. This may be due to the non-deformability of the wood block chosen. These authors also reported the importance of presentation of the enrichment; keeping the enrichment clean and in sight increased the pigs' frequency of interaction. In the current study, by using the dispenser, the wood was kept from the ground, reducing the possibility of soiling. Moreover, being edible and destructible also means that the wood was somewhat renewable. Fresh wood dropped down through the dispenser as the lower part of the wood was consumed, which acted as a self-replenishing mechanism and provided a novel surface for interaction. As the wood dropped down, the shape of the wood post also changed, as demonstrated by the variation in circumference. The combined effects of these features provide possible explanations as to why the wood posts sustained the pigs' attention for a longer period. In the spruce pens, when a post was used up, a new one was replenished, which also enhanced the novelty effect. The Scots pine was routinely used on the farm in the grower stage as enrichment, which might explain why it showed a trend of reduced interaction over time compared to the other 3 types of wood, which were only introduced to the pigs in the experiment from 12 weeks onwards. Thus, the different wood types might have been regarded “sufficiently different” by the pigs, resulting in the different patterns of interaction frequency.

The price for all wood types used was similar at the time of the study (January to June 2016), but due to the different rate of weight reduction, using spruce cost 9 times more than beech and 4.5 times more than Scots pine and larch. D’Eath et al. (2016) carried out a cost comparison of different scenarios of housing and enrichment provision with their respective capacity to manage tail biting. That study reported that in a partly slatted standard housing with docked pigs (“standard docked scenario”), the enrichment cost was estimated based on €0.17 per pig during the finisher stage, which was similar to the cost of spruce in the current experiment. Based on these results, and the fact that the “standard docked scenario” had a lower tail biting outbreak probability than non-docking, using spruce to manage tail biting could be economically feasible in a slatted system with docked pigs (D’Eath et al., 2016). Nevertheless, docking is not permitted routinely in the EU, and thus our results with regard to cost are only applicable in a docked situation, as when pigs are not docked an increased enrichment allowance is necessary (Chou et al., 2018). A significant factor which could hamper the farmer’s willingness to adopt this management approach would be a necessity to continual replenishment of the wood posts and the extra labour time that could incur.

During the course of the experiment, there were no serious tail and ear biting incidents, and the lesions observed were mostly mild superficial scratches. This might in part explain why there was no difference between wood types with regard to the pig-based measures. The overall recorded activity was the lowest in week 8, which could be a result of pigs' heavier weight, and consequently less space available in the pen, in agreement with previous studies (Van de Weerd et al., 2005; Scollo et al., 2013). The highest level of tail biting in the study occurred in week 5, which also corresponds to previous research (Van de Weerd et al., 2005; Schrøder-Petersen and Simonsen, 2001), However Scollo et al. (2013) found that when finisher pigs were reared to reach a heavier weight, tail biting increased at week 14. It is widely acknowledged that the triggers leading to the onset of tail biting are multifactorial (D'Eath et al., 2014), with stocking density (as well as other factors such as tail length, ventilation, genetics etc.) playing a role in increasing biting behaviours.

The highest frequency of ear biting was observed in week 7. Very little is known about the development of ear biting in pigs in the published literature. In terms of lesion scores, the lowest tail lesion score was recorded at the beginning of the experiment which supported the behavioural data, as this was when the lowest level of tail biting was observed. Entering a new environment (i.e. the finisher pens) with a greater space allowance per pig could have diverted the pigs' attention away from tail biting. Conversely, ear lesions were more severe at the beginning and week 6 of the experiment. The former might be caused by the stress of mixing upon entering the finishing stage and the latter might be from more frequent ear biting behaviour observed during that period. As the final lesion scores were obtained in week 6, any interpretation of the relevance of such findings at this time is limited.

Tear staining has been shown in laboratory rats to be an indicator of social stress (Mason et al., 2004). In pigs, there is the suggestion that the occurrence of tear stains could be a symptom of nasal inflammation (such as atrophic rhinitis) or exposure to ammonia (Done et al, 2012; Register et al, 2012). However, DeBoer et al. (2015) found that laboratory pigs housed in visually isolated pens had significantly higher tear staining scores than pigs with social visual stimulation, suggesting a link to stress, in this case associated with isolation. Although in the current study only one eye from each pig was scored on each recording occasion, DeBoer et al. (2015) scored both, and found the results consistent between eyes. In the current study, all pigs were group housed in similar conditions with no known issue of nasal disease on the farm, and thus any potential differences in tear staining between treatments could have been due to the wood type.

Similar to what DeBoer et al (2015) found, there was no effect of enrichment treatments on tear staining, but the positive but weak correlation between tear staining and ear and tail lesion scores could suggest the pigs were under higher level of stress resulting from more biting. Telkänranta et al. (2016) also reported a positive correlation between tear staining and the occurrence of tail and ear lesions, albeit similarly with a low coefficient. These authors also noted the great variation of scores within pen. They suggested that tear staining has potential as an indicator to identify individual pigs with particularly high stress levels within a pen, although further work is needed to determine the cause of the high level of variation. The variation between individual pigs may itself be a resultant from the level of tear staining a pig can generate, rather than the stress it experiences. Feedback from the farm staff revealed a high interest in tear staining scoring as it is relatively easy to notice during routine inspection. This measure might thus have the potential to be utilised as a practical on-farm inspection tool if further validation of its effectiveness in detecting higher level of stressful conditions, such as excessive tail and ear biting, could be obtained.

Some research has suggested tail posture could be used as a prediction of tail biting outbreaks (Zonderland et al, 2009; Paoli et al, 2016). In the current study the positive correlation between tail lesion and tail posture was significant but also with a low strength. This could be due to the fact that no major tail biting outbreak occurred, and neither were serious tail lesions observed during the experiment. Moreover, as the Trowbridge housing prevented the tail posture being scored outside the pen, the results could have been affected by the pig's reaction to human approach since the tail posture was also shown to indicate the emotional state of pigs (e.g. fear and excitement) (Kiley-Worthington, 1976; Reimert et al., 2013). Nevertheless, as pointed out by Paoli et al. (2016), even in docked pigs, pointing the tails downwards towards the body could work as a defensive measure if the pigs were prone to being victims of biting.

In the current study, and even in the absence of severe tail biting occurrences, the tail posture in docked pigs could still be a relevant measure to detect ongoing prevalent tail lesions in the pens.

Conclusion

The performance of different wood types varied with regard to durability and attraction to pigs: softer wood was less durable but it attracted pigs' attention more. Thus when using wood as environmental enrichment for pigs, the wood type chosen should be taken into consideration, as softer types of wood are likely to sustain more frequent and longer attention from pigs. Other traits of wood, such as odour, shape, and taste, should be further explored with regard to attraction to pigs. Nevertheless, there was no difference in wood types with regard to effectiveness in reducing harmful behaviours or lesions, and the overall level of tail biting observed was low. No effect was found on production measures. Wood can be a potentially suitable enrichment material to manage tail biting in docked pigs when appropriate wood type is in use, but further work is still needed to verify its performance in conditions with a higher risk of tail biting.

Conflict of interest statement

The authors declare no conflict of interest.

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Figure captions

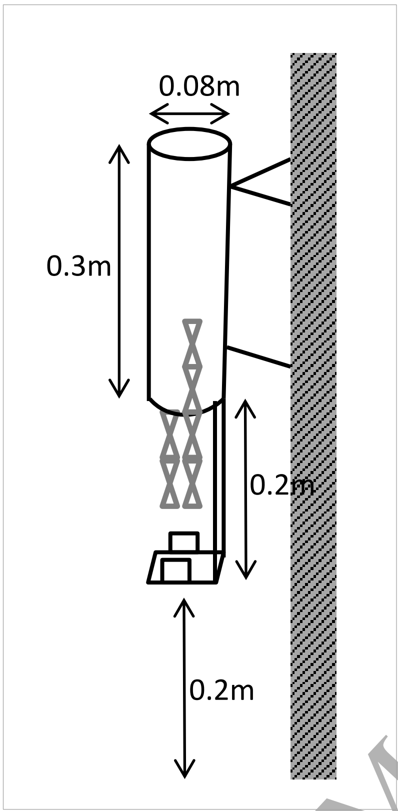

Figure 1. Schematic diagram of the wood dispenser.

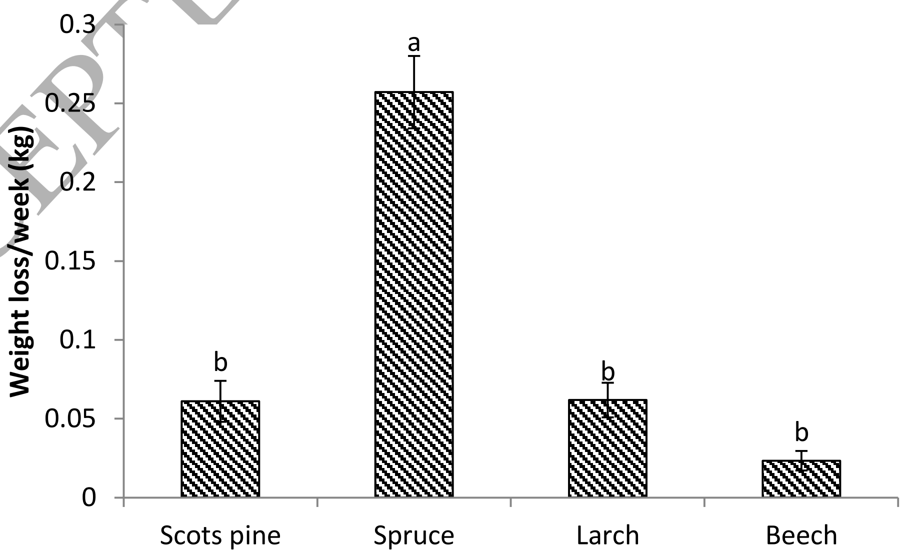

Figure 2. Weight loss of wood posts per week between wood types (LSmean±SEM). $F_{(3, 22.6)}$=8.79, P<0.001. Different letters denote significant differences determined using Tukey-Kramer test.

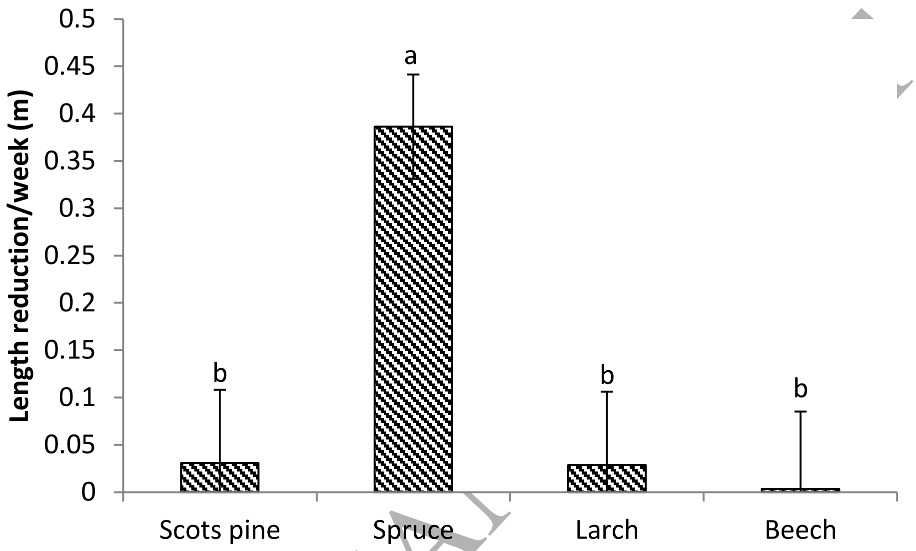

Figure 3. Length reduction of wood posts per week between wood types (LSmean±SEM). $F_{(3, 27.9)}$=17.8, P<0.001. Different letters denote significant differences determined using Tukey-Kramer test.

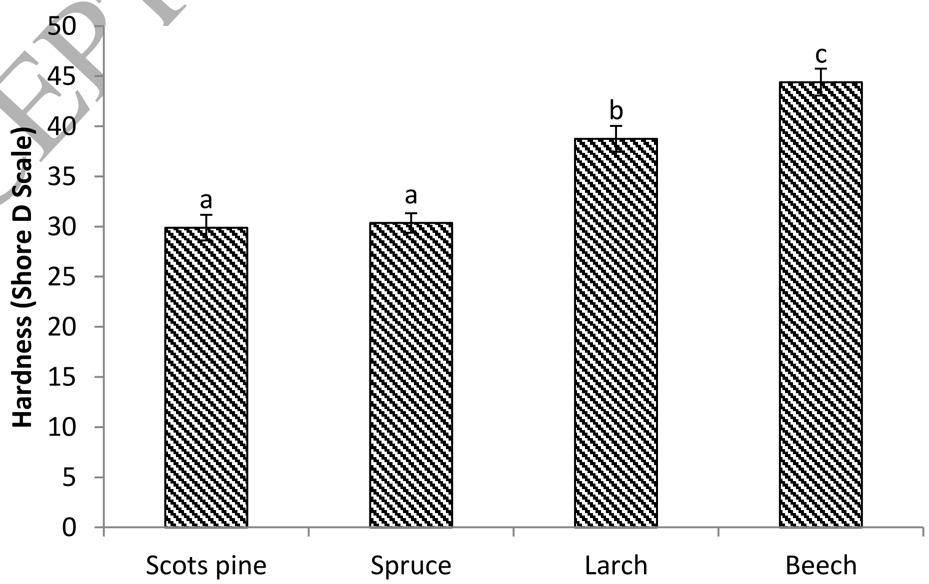

Figure 4. Hardness of wood posts between wood types (LSmean±SEM). $F_{(3,36.8)}$=34.03, P<0.001. Different letters denote significant differences determined using Tukey-Kramer test.

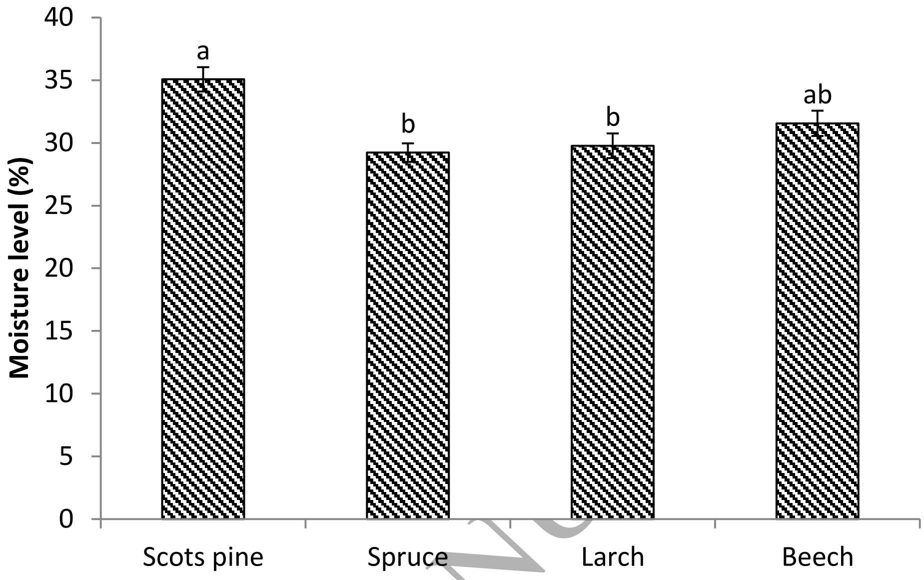

Figure 5. Moisture level of wood posts between wood types (LSmean±SEM). $F_{(3,28)}$=8.47, P<0.001. Different letters denote significant differences determined using Tukey-Kramer test.

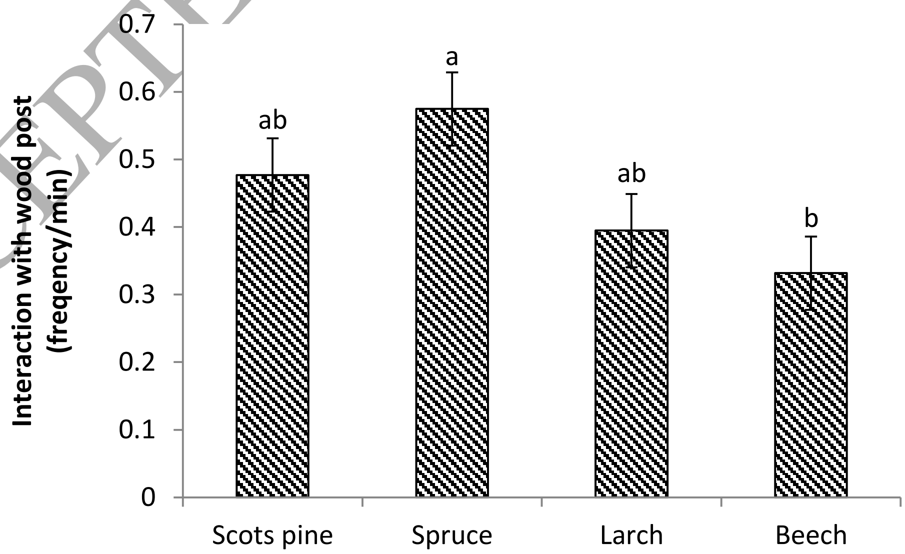

Figure 6. Frequency of interaction with wood posts between wood types (LSmean±SEM). $F_{(3, 81.2)}$=3.46, P<0.05. Different letters denote significant differences determined using Tukey-Kramer test.

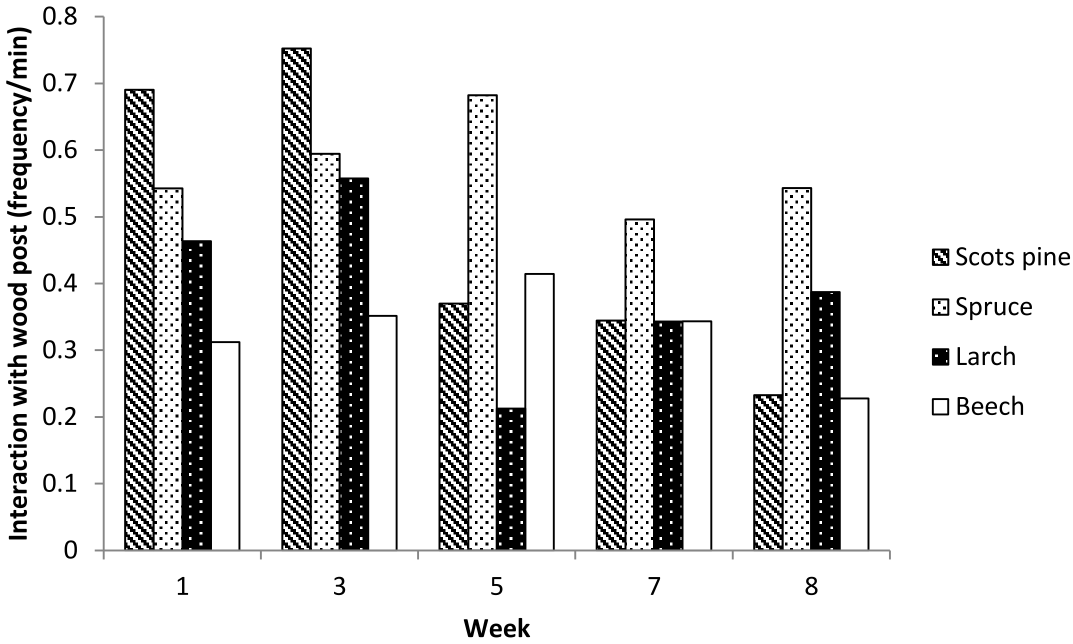

Figure 7. Frequency of interaction with the wood post per pen across time between wood types (LSmean±SEM). There was no significant difference between weeks or interaction between week and treatment.

Tables

Table 1. Ethogram for direct behaviour observation. All behaviours were recorded as frequencies.

Behaviours	Description
Tail biting	Tail in the mouth of another pig: ranges from tail being gently manipulated to tail being chewed/bitten
Ear biting	Ear in the mouth of another pig: ranges from ear being gently manipulated to being chewed/bitten
Flank biting	Oral manipulation including bites directed towards the flank of another pig
Belly nosing	Rhythmic up-and-down movement of the snout of one pig rubbing the belly of another
Fighting	Mutual pushing parallel or perpendicular, ramming or pushing of the opponent with the head, with or without biting in rapid succession
Mounting	Placing hooves on the back of another pig with or without pelvic movement
Play	Play behaviour, scampering, jumping/running around
Using wood	Any form of oral/nasal manipulation on the wood part of the enrichment
Using dispenser	Any form of oral/nasal manipulation on the dispenser part of the enrichment, including chains on each side and the metal dispenser itself

Table 2. Tail lesion scoring system

Score	Description
0	No evidence of lesions
1	Healed or mild scratches/punctures
2	Scratches and punctures that are wider than a pinhead with some visible redness
3	Swelling, fresh blood, apparent redness, possible pus and necrotic tissue and possible signs of amputation

Table 3. Ear lesion scoring adopted from Telkänranta et al. (2014). Category 3 is shown in bold as it was added in for the current experiment additional to the original system.

Score	Description
0	Undamaged ears.
1	Superficial scratches.
2	Evidence of recent bleeding.
3	**Bloody and red (substantial cuts and bleeding)**
4	Part of an ear missing.

Table 4. Behaviour frequencies (/min) observed between different wood types (LSmean±SEM). Different letters denote significant differences picked up by Tukey-Kramer test.

Behaviour	Treatment					F value	P-value
	Scots pine	Spruce	Larch	Beech	SEM		
Using enrichment	1.0837	1.1739	1.0011	1.0354	0.08	0.82	NS
Using wood	0.4777 [ab]	0.5714[a]	0.3957 [ab]	0.3279[b]	0.06	3.46	<0.05
Using dispenser	0.6084	0.5917	0.6085	0.6956	0.05	0.85	NS
Tail biting	0.4344	0.3827	0.3647	0.3532	0.65	0.5	NS
Ear biting	0.2125	0.1542	0.2417	0.1833	0.03	1.49	NS
Flank biting	0.1674	0.2201	0.247	0.2378	0.03	1.46	NS
Belly nosing	0.1235	0.1363	0.1201	0.08033	0.03	0.49	NS
All harmful*	0.9377	0.8921	0.9708	0.8575	0.07	0.47	NS
Fighting	0.2041	0.1833	0.1415	0.1959	0.03	0.73	NS
Mounting	0.2881	0.2536	0.3093	0.1827	0.05	1.2	NS
Play	0.2418	0.2172	0.2871	0.2111	0.05	0.41	NS

* All harmful behaviour = Tail biting + ear biting +flank biting + belly nosing

Table 5. Behaviour frequencies (/min) observed in all pens across time (LSmean±SEM). Different letters denote significant differences picked up by Tukey-Kramer test.

Behaviour	Week						F value	P-value
	1	3	5	7	8	SEM		
Using enrichment	1.18[a]	1.36[ab]	1.15[ab]	0.95[bc]	0.72[c]	0.07	11.52	P<0.001
Using wood	0.50	0.56	0.42	0.38	0.35	0.06	2.31	P=0.06
Using dispenser	0.67[ab]	0.79[a]	0.74[a]	0.56[b]	0.37[c]	0.04	16.12	P<0.001
Overall	2.78[a]	3.07[a]	3.03[a]	2.74[a]	1.71[b]	0.14	18.13	P<0.001
Tail biting	0.23[a]	0.35[a]	0.64[b]	0.39[a]	0.31[a]	0.05	8.47	P<0.001
Ear biting	0.22[a]	0.15[a]	0.09[a]	0.39[b]	0.14[a]	0.03	11.44	P<0.001
Flank biting	0.18[ad]	0.33[bc]	0.08[d]	0.32[ac]	0.18[ad]	0.03	8.08	P<0.001
Belly nosing	0.21[a]	0.06[bc]	0.02[c]	0.17[ab]	0.12	0.04	4.67	P<0.01
All harmful*	0.85[a]	0.90[a]	0.82[a]	1.26[b]	0.75[a]	0.08	6.53	P<0.001
Fighting	0.10[ac]	0.23[ab]	0.37[b]	0.16[ac]	0.04[c]	0.04	12.2	P<0.001
Mounting	0.27	0.28	0.35	0.22	0.17	0.05	1.97	NS
Play	0.38[a]	0.29[ab]	0.34[ab]	0.15[bc]	0.05[c]	0.06	6.07	P<0.001

* All harmful behaviour = Tail biting + ear biting +flank biting + belly nosing.

Table 6. Average lesion scores recorded across time (LSmean±SEM). Different letters denote significant differences picked up by Tukey-Kramer test.

Score	Week					F value	P-value
	0	2	4	6	SEM		
Tail lesion	0.68^{a}	0.81^{b}	0.90^{b}	0.90^{b}	0.04	11.78	P<0.001
Ear lesion	1.12^{a}	0.96^{b}	1.08^{ab}	1.12^{a}	0.06	3.2	P<0.05
Tear staining	1.79^{a}	2.05^{b}	2.21^{b}	2.59^{c}	0.06	34.99	P<0.001

Supplementary material: Picture of Trowbridge housing

Discussion of Chapter 3

This study addressed the first objective of this thesis, which was to identify whether different wood species affect pigs' interaction, and which species of wood, based upon their physical characteristics, is most suitable for use as environmental enrichment. It showed that different wood species did perform differently in terms of attracting interaction from the pigs. Pigs preferred to interact more with spruce, which was likely due to its property of being the softest, rendering it more destructible. Docked pigs were used in this study, so the overall level of tail biting was low, and all damaging behaviours and physical scores did not differ between treatments. Moreover, since the study was conducted on a commercial farm, a simplified pen-level behaviour observation was used (all-occurrence sampling for 3 minutes on two occasions every two weeks by two observers), and the lesion scores were also recorded at the pen level without identifying individual animals. In order to have a clearer picture of the differences in behaviour and lesion scores within a pen regarding the species of wood, a more detailed behaviour observation and lesion scoring methodology were used in the next chapter (**Chapter 4**).

Correction: The low co-efficient and high p-value (r_S=0.076 P<0.001) in the first line on page 65 was the results calculated at the individual level. The very low co-efficient with high p-value was possibly due to the very weak correlation with a higher sample size (N=3170). Although the lesion score was generally analysed at the pen level, the score for individual pig was scored independently, and therefore the correlation between scores could be done at the individual level. If done at the pen level, the co-efficient was higher as r_S=0.286, P<0.001.

Chapter 4 Enrichment use in finishing pigs and its relationship with damaging behaviours: comparing three wood species and a rubber floor toy

This chapter is the manuscript submitted to *Applied Animal Behaviour Science* on 11 Aug 2019: Chou J.-Y., D'Eath R.B., Sandercock D.A. and O'Driscoll K. Enrichment use in finishing pigs and its relationship with damaging behaviours: comparing three wood species and a rubber floor toy. 2019. Under review. The locations of the figures and tables were moved to where they were first mentioned in the main text to facilitate readability.

This chapter had been previously presented as a poster in: **Chou, J.-Y.**, D'Eath, R.B., Sandercock, D.A. and O'Driscoll, K. 2019. Individual variation of enrichment use in finishing pigs with one point source item and the impact on tail biting outcome. Proceedings of the 53rd Congress of the International Society for Applied Ethology (ISAE) 5-9 August, Bergen, Norway.

Introduction to Chapter 4

Following up on the previous chapter, this chapter describes a further investigation which was conducted to evaluate three selected wood species, in addition to a comparison with an inorganic enrichment material, a rubber floor toy. Unlike the previous study, which took place on a commercial farm and therefore only pen-level data were collected, in this study, detailed continuous behaviour observation was possible as video recording was carried out. Moreover, all physical scores were recorded on individually identified pigs. A physiological measure of salivary cortisol was also taken as supporting evidence, and a thorough examination on the mouth and gum area during carcass inspection was conducted. I contributed to the experimental design, data collection, statistical analysis, data presentation and original draft preparation. Part of the data collection was assisted by the intern student Madeleine Munkonka.

Sample size calculation was required as part of the ethical approval process (TAEC110/2016). It was estimated using the GLMPOWER procedure in SAS v9.3, with similar parameters used as the previous study (**Ch.3**): a difference of 0.9 with an estimated standard deviation of 0.5, a significance level of $p < 0.05$, and a power value of 0.8 were used.

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Article Type: Research Paper

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Abstract: Environmental enrichment in pig housing is a legal requirement under current EU legislation, but some recommended loose materials may cause obstructions in fully-slatted systems. Wood is an organic material that could be compatible with slatted systems. This study investigated enrichment use in finishing pigs (three wood species and a rubber floor toy) and explored the relationship between use and damaging behaviours, and physiological and physical measures of stress and injury. Individual variation in enrichment use within pen was also investigated. Pigs (12 weeks old; week 0) were housed in 40 pens of seven pigs (n = 280). One of four different enrichment items (one spruce, larch, or beech wooden post, or rubber floor toy) was randomly assigned to each pen (10 pens/treatment). The behaviour of each individually marked pig was observed continuously from video recordings taken on six different occasions (twice during week 2, 4 and 7; 1 hour per occasion). Individual tail/ear lesion and tear staining scores were recorded every 2 weeks. Saliva samples for cortisol analysis were obtained from three focal pigs per pen every 2 weeks. These focal pigs were selected based on the latency to approach the experimenter on the first sampling day and classified as 'Approach', 'Neutral' or 'Avoid'. Carcasses were inspected for tail lesions and potential oral damage. Time spent using enrichment was higher in pigs with spruce and rubber toy than with larch and beech ($P < 0.001$). Spruce was consumed the most quickly and was the softest of the wood species ($P < 0.001$). High use of spruce was not due to consistent high use by certain pigs. No treatment effect on any other behaviour was recorded, but enrichment use was positively correlated with damaging behaviours at pen level ($P < 0.001$). Spruce pigs had slightly more severe tail lesion scores than Beech ($P < 0.05$). Salivary cortisol did not differ between treatments but was higher in 'Avoid' than 'Approach' pigs ($P = 0.04$). No clear oral damage that could be attributed to using wood was found. By investigating enrichment use at both pen and individual level, a more complete picture was obtained of how pigs used the enrichment. Wood appears to be a safe material to use as

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environmental enrichment for pigs and a softer wood species was preferred by pigs with equal preference for the rubber floor toy.

- Spruce and the rubber floor toy were used by pigs more than larch and beech
- No obvious oral damage was found post-mortem that could be solely attributed to wood splinters
- High use of spruce was not attributable to consistent high users
- Enrichment had no effect on salivary cortisol concentration

Enrichment use in finishing pigs and its relationship with damaging behaviours: comparing three wood species and a rubber floor toy

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Abstract

Environmental enrichment in pig housing is a legal requirement under current EU legislation, but some recommended loose materials may cause obstructions in fully-slatted systems. Wood is an organic material that could be compatible with slatted systems. This study investigated enrichment use in finishing pigs (three wood species and a rubber floor toy) and explored the relationship between use and damaging behaviours, and physiological and physical measures of stress and injury. Individual variation in enrichment use within pen was also investigated. Pigs (12 weeks old; week 0) were housed in 40 pens of seven pigs (n = 280). One of four different enrichment items (one spruce, larch, or beech wooden post, or rubber floor toy) was randomly assigned to each pen (10 pens/treatment). The behaviour of each individually marked pig was observed continuously from video recordings taken on six different occasions (twice during week 2, 4 and 7; 1 hour per occasion). Individual tail/ear lesion and tear staining scores were recorded every 2 weeks. Saliva samples for cortisol analysis were obtained from three focal pigs per pen every 2 weeks. These focal pigs were selected based on the latency to approach the experimenter on the first sampling day and classified as 'Approach', 'Neutral' or 'Avoid'. Carcasses were inspected for tail lesions and potential oral damage. Time spent using enrichment was higher in pigs with spruce and rubber toy than with larch and beech ($P < 0.001$). Spruce was consumed the most quickly and was the softest of the wood species ($P < 0.001$). High use of spruce was not due to consistent high use by certain pigs. No treatment effect on any other behaviour was recorded, but enrichment use was positively correlated with damaging behaviours at pen level ($P < 0.001$). Spruce pigs had slightly more severe tail lesion scores than Beech ($P < 0.05$). Salivary cortisol did not differ between treatments but was higher in 'Avoid' than 'Approach' pigs ($P = 0.04$). No clear oral damage that could be attributed to using wood was found. By investigating enrichment use at both pen and individual level, a more complete

picture was obtained of how pigs used the enrichment. Wood appears to be a safe material to use as environmental enrichment for pigs and a softer wood species was preferred by pigs with equal preference for the rubber floor toy.

Keywords

Environmental enrichment, wood species, rubber toy, fully-slatted system, damaging behaviour

Highlights

- Spruce and the rubber floor toy were used by pigs more than larch and beech
- No obvious oral damage was found post-mortem that could be solely attributed to wood splinters
- High use of spruce was not attributable to consistent high users
- Enrichment had no effect on salivary cortisol concentration

1. Introduction

In the EU it is mandatory to provide pigs with suitable materials to explore and manipulate, regardless of the housing system (European Union, 2009). However, on fully-slatted floors the choice of environmental enrichment is limited, since loose materials can be wasted as they fall through the slats quickly, or may block the slats or potentially disrupt the slurry removal system beneath, which depends on an unobstructed flow of drainage of liquid manure. A survey of expert opinion suggested that suitable enrichment for pigs should provide occupation and allow exploration, and the materials used should be rootable, manipulable, and chewable (Bracke, 2006). Wood is an organic option that could potentially satisfy these criteria, depending on the characteristics and presentation of the wood (Barbari et al., 2017). It is acceptable to producers in Ireland due to its convenience and durability, which means it is economically advantageous (Haigh and O'Driscoll, 2016). However, concerns were also raised as to whether dried wood could cause splinters and become unsafe for pig to use (European Commission, 2016), which requires further investigation.

Recently wood has gained increasing attention in research as a point-source enrichment material for pigs, especially in relation to damaging behaviours such as tail biting. Previously, we have found that softer wood species used as enrichment material generated higher levels of interaction, and a higher rate of consumption than harder species did, from docked finishing pigs (Chou et al., 2018). At the same time, however, tail lesion scores and damaging behaviours were similar across treatments. Telkänranta et al., (2014) reported that undocked finishing pigs interacted more with fresh branches of birch (*Betula pendula* and *Betula pubescens*) compared to chains, and wood also reduced the prevalence of tail injuries, albeit with no difference in tail biting behaviour. However, Nannoni et al., (2018) compared undocked finisher pigs given three poplar (*Populus*) wood posts to those given a steel chain, and they found less interaction with the enrichment, no difference in tail biting behaviour, and higher tail lesion scores in pigs given wood. In that study, the wood was provided horizontally in an elevated rack. A more recent study showed poplar logs were more effective than hanging chains in attracting interaction from finishing pigs, but only reduced tail biting when suspended by chains but not when presented loose on the floor (Giuliotti et al., 2019). However, the authors did not specify if the pigs they used were docked or undocked.

Salivary cortisol is a non-invasive and efficient method to assess the stress response in animals, and can be used as a basic physiological measure to supplement behavioural observation and physical scores (Casal et al., 2016; Merlot et al., 2012; Scollo et al., 2014; Smulders et al., 2006). Some studies have found enriched housing increased salivary cortisol concentration in pigs (de Groot et al., 2000; de Jong et al., 2000, 1998; Morrison et al., 2007). However, factors such as activity level, rearing background and social competition can also influence salivary cortisol concentration (Casal et al., 2016; Merlot et al., 2012). It is not certain if point-source enrichment items would affect cortisol concentration, or if organic and non-organic item would differ in this regard.

Most of the enrichment studies mentioned above used group level comparisons of enrichment use, as is the case in the majority of enrichment studies. More recently, Larsen et al., (2019) used behaviour observation at different levels (pen vs focal animal) and with various sampling methods (continuous, one-zero and instantaneous) to investigate in more detail the length of an interaction bout, and the proportion of individuals within a pen that interacted with the enrichment. Indeed, there has been growing interest in how individual differences in farm animals can affect their behaviour and welfare (Finkemeier et al., 2018). Although recent research has investigated how environmental enrichment can affect farm animals' emotional state (Boissy and Erhard, 2014), how their individuality may influence their enrichment use is less discussed.

This study investigated enrichment interaction in tail-docked finishing pigs provided with one point-source enrichment item per pen. The study compared three wood species and a rubber floor toy, with regard to performance of damaging behaviours, and selected physical outcomes. As a secondary aim, this study further explored the within-pen variation in pigs' interaction with the enrichment.

2. Materials and methods

The experiment was conducted at the Pig Research Facility in Teagasc, Moorepark, Ireland and approved by the Teagasc Animal Ethics Committee (TAEC110/2016).

2.1 Animals and housing

A total of 280 finisher pigs (Maxgrow × Landrace × Large White, Hermitage Genetics, Ireland) arrived at the research farm over two batches, with the second batch arriving two weeks after the first batch was sent for slaughter. All pigs arrived at 12 weeks of age. Pigs had been tail-docked and teeth-clipped at the breeding farm and male pigs were not castrated. On arrival at the research facility, pigs were individually tagged, weighed and their tails checked for lesions and blood. The experiment lasted for 10 weeks, after which time the pigs were sent to the slaughterhouse for post-mortem carcass inspection.

The finisher pens measured 2.37 × 2.36 m and had a fully-slatted floor, except for a 1.21 × 0.77 m area around the feeding trough (1.00m L × 0.32m W × 0.21m H) which was covered by a rubber mat to prevent food waste. The temperature was maintained at around 20°C by passive ventilation with three main inlets on the ceiling and smaller inlets along the wall, and the room was artificially lit at around 130 lux for 12/24 hours. Pigs were fed a standard liquid diet *ad-libitum* by sensor feeding. A nipple drinker was located near the trough at 0.3 m above ground to provide *ad libitum* access to fresh water.

2.2 Experimental treatments

After pigs were weighed individually, they were assigned to blocks on the basis of sex and weight (10 blocks of 4 pens: 4 blocks in batch 1 and 6 blocks in batch 2); each pen housing 7 pigs. Within a block, the differences between body weights and pen locations were kept at minimum between pens (Supplementary I). There were 7 pigs per pen, so half of the pens had 4 males and 3 females, and the other half had 4 females and 3 males. Pigs whose tails had inflammation, infection or fresh blood recorded on arrival were not used. The average starting weight was 35.82 ± 0.16 kg for batch 1 and 31.91 ± 0.34 kg for batch 2.

Within a block of 4 pens, each pen was randomly assigned to one of 4 different treatments (10 pens per treatment) based on the enrichment item in the pen: one rubber floor toy (Easyfix, Ballinasloe, Ireland, average starting weight 2.18kg), one spruce (*Picea sitchensis*) wooden post (average starting length 1.097m, weight 1.366kg, dimension 0.231m), one larch (*Larix decidua*) post (average starting length 1.216m, weight 3.167kg, dimension 0.267m), or one beech (*Fagus sylvatica*) post (average starting length 1.214m, weight

2.858kg, dimension 0.237m). All wooden posts were cuboid in shape. The enrichment to pig ratio was 1:7 in all pens.

All wooden posts were standardised and sourced from a local sawmill (Glennon Bros. Cork Ltd., Fermoy, Ireland) and were kiln dried but not treated with any chemicals. The posts were dispensed in the pens using a 0.65m L × 0.18m W × 0.11m D white plastic Funbar wood holder (Jetwash Ltd., Carrigallen, Ireland), mounted on the wall at around a 45° diagonal angle (top-right to bottom left), with the bottom of the holder at 0.25 m above ground (Figure 1A). The position of the wood dispenser was based on a previous pilot study suggesting that pigs used wood more when it was provided in a diagonally installed dispenser than when presented vertically. The wood posts were placed into the dispenser and the base touched the floor. The pigs were able to access ~0.35 m of wood below the holder and ~0.21 m above, although they primarily made use of the lower part. The rubber floor toy was made of soft rubber with a spiked shape and placed on the floor in the pen (Figure 1B). The toy was movable and the pigs could pick it up and carry it in their mouth by the spiked arms. All items were chewable and rootable.

2.3 Enrichment measurements

Before each wood post was provided, the following measurements were taken: 1) Length (m), 2) Weight (kg), 3) Dimension (m), taken at 0m, 0.1m, 0.2m, and 0.4m from the bottom of the post), 4) Hardness (shore D scale, measured by a durometer AD-300, Checkline Europe, Enschede, the Netherlands), taken at three randomly selected spots at 0m, 0.1m, 0.2m, 0.4m, and 0.6m

Figure1

A)

B)

Figure 1. Picture of A) Wood dispenser as located in the pen and B) Rubber floor toy.

from the base of the post (15 readings/post), 5) Moisture level (%, using Hydromette BL-H-40, Gann, Germany), taken at 0m, 0.1m, 0.2m, 0.4m, and 0.6m from the base of the post. Subsequently all measurements were taken every week. Whenever a wood post was consumed by the pigs and shortened to the extent that it could no longer stay in the dispenser and slid on the ground, a new post was measured and replaced the old one. The weight of the remains was also recorded. The rubber floor toys were weighed before the start of the trial and again at the end.

2.4 Animal-based measures

2.4.1 Behaviour recordings

In experimental week 2, 4 and 7, the pens were continuously video-recorded (QVIS HDAP400 CCTV cameras and a Pioneer-16 digital recorder case, CCTV Ireland, Kildare, Ireland) for 24 hours/day on 3 consecutive days. Due to the layout of the house, only half of the pens (2 blocks of pens in batch 1 and 3 blocks in batch 2, detailed blocking plan see Supplementary I) could be covered at one time. After the first half of the pens were recorded, the cameras were then switched to video record the other half of the pens over a 24-hour period for another 3 consecutive days. Before recording commenced, each pig in a pen was marked with a distinct colour on their back by animal marker sprays (Coyle Vet, Galway, Ireland) for individual identification, and the colour was reapplied whenever necessary. This was the case except for batch 1 in week 2, where no individual markings were made due to technical issues and therefore only pen-level data were available for analysis.

In order to identify when most activities occurred, six randomly selected 24-hour video clips were scanned every 3 minutes by counting the number of pigs standing up and lying down. The hour of day when the most pigs were standing up was from 12:00 h to 13:00 h, and therefore this time was selected for subsequent behaviour sampling. All pens were observed continuously during this period on two different days during each of the recording weeks (6 hours of recording/pen in total), using the ethogram in Table 1. The video observations were completed using the Observer XT (Ver. 14, Noldus, Wageningen, the Netherlands), with the duration and frequency of all behaviours recorded at the pig level when individual identification was available.

2.4.2 Saliva sampling

In week 2, 4, 6, 8, and 10, saliva samples were collected on the same day between 1000 – 1200 h from 3 focal pigs in each pen. A stratified randomisation method was used to select the focal pigs based on the latency to approach the experimenter when collecting the first sample in order to obtain a good representation of the pigs within a pen. One pig which approached the experimenter voluntarily (“Approach”), one pig which stayed at the back of the pen showing avoidance (“Avoid”), and one pig in between the two (“Neutral”) were selected for the subsequent saliva samplings. All samples were taken using a biocompatible synthetic swab (Salivette, Sarstedt, Wexford, Ireland) presented on tweezers for the pigs to chew on. The salivary samples taken (approximately 0.5 ml) were preserved in the swab storage tubes (Salivette, Sarstedt, Wexford, Ireland) and were then centrifuged at 1,500 rpm and frozen at -20ºC. The samples were

Table 1. Ethogram for video observation. All behaviours were recorded continuously as duration of time and frequency.

Behaviours	Description
Tail biting	Tail in the mouth of another pig: ranges from tail being gently manipulated to tail being chewed/bitten (Distinguished between standing up or sitting/lying down)
Ear biting	Ear in the mouth of another pig: ranges from ear being gently manipulated to being chewed/bitten (Distinguished between standing up or sitting/lying down)
Play	Play behaviour, scampering, jumping/running around
Enrichment use	Any forms of oral/nasal manipulation on the wood part of the enrichment
Aggression over enrichment	Hostile encounter for the access of enrichment including aggressive biting, Head knocking and parallel pressing

later analysed using ELISA (Enzyme-linked immunosorbent assay, Salimetrics, Carlsbad, CA, USA; 96-well plate with assay sensitivity of 0.007 μg/dL and assay range between 0.012-3.000 μg/dL) to determine the cortisol concentration in the saliva.

2.4.3 Physical scores

Pigs were scored individually every two weeks for the following measures: Tail lesions were recorded using two different systems: the scoring system adapted from Hunter et al., (1999) (0: no damage, 1: mild, 2: moderate, 3: severe) and the system developed by the FareWellDock consortium, which consisted of separate scores for damage (0: no lesion, 1: bite marks, 2: open wound, 3: swollen bite wounds) and presence of blood (0: no blood, 1: black scar, 2: older red blood, 3: fresh blood) (Chou et al., 2019b). Ear lesions were recorded on a 0-4 scale (0: no lesion, 1: superficial scratches, 2: evidence of recent bleeding, 3: substantial cuts and bleeding, 4: part of ear amputated; modified from Telkänranta et al., 2014). Tear staining was evaluated with the DeBoer-Marchant-Forde Scale (0: no visible stains, 1: barely detectable stains not extending below eyelid, 2: visible stain about < 50% in ratio to the eye, 3: visible stain about 50-100% in ratio to the eyes, 4: visible stain > 100% in ratio to the eye but not extending below the mouth line, 5: visible stain extending below the mouth line; DeBoer et al., 2015). Left and right eyes were scored separately.

2.4.4 Carcass data

All pigs were tattooed with individual identification before being sent for slaughter. In the slaughterhouse, tail lesions visible on the carcass were recorded (0-4 scale, 0: no lesion, 1: healed/mild lesions, 2: evidence of chewing and puncture wounds, 3: signs of swelling and infection, 4: partial/total loss of tail; Harley et al., 2012). In addition, the inside of the mouth was examined for the presence or absence of possible damage to the gums and tongues caused by wood consumption.

2.5 Data analysis

Data were analysed using Statistical Analyses System (SAS, version 9.1.3, 1989, SAS Institute Inc., Cary, NC, USA). Linear mixed models (PROC MIXED) were used to analyse continuous data such as wood measures, duration of behaviour and salivary cortisol. Differences between least square means were investigated using the t-test, followed by the Tukey-Kramer adjustment for multiple comparisons. Residuals were checked for normality and the data were transformed using logarithms where necessary.

For analyses of wood measures, treatment, week, batch and the interaction between week and treatment were included as fixed effects, week as a repeated effect and block within batch as a random effect. As moisture and hardness measures were taken at different positions on the wooden posts, position was also included as a fixed effect. The dimension was analysed as the variation of the values between measures at different positions on the wooden posts, so the position was included as a fixed effect as well.

Data from behaviour observations on the two different days within an observation week were averaged. In order to include the data for batch 1 in week 2 (when individual pig identification was not available), behaviour data were analysed at both pen-level and individual level; the pen-level data were mainly used to compare differences between treatments, whereas the individual-level data were used to explore the within-pen variation. For pen-level analyses, the response variable was the duration of a behaviour per hour per pig. Fixed effects included treatment, week, batch, and the interaction between week and treatment. Week was considered a repeated effect and block within batch as a random effect. The relationship between enrichment interaction and damaging behaviours (tail biting, ear biting and the two combined) were examined using Pearson's correlation, using the log-transformed data of pen-level average duration on each observation day.

For individual-level analyses, the duration of each behaviour per hour for each pig was the response variable. Treatment, week, batch, sex and the interaction between week and treatment were included as fixed effects, week a repeated effect and block within batch as a random effect. To further compare the differences between types ("Approach", "Neutral" or "Avoid") of focal pigs, their data was analysed separately by adding the "type" as a fixed effect. Kendall's coefficient of concordance was calculated for individual pigs in each treatment to test the level of agreement in each pig's enrichment use between recording occasions. For enrichment interactions, the bout length and the proportion of pigs per pen that interacted with the enrichment was also calculated and analysed similarly to the total duration of interaction during the recording period.

Salivary cortisol was right-skewed due to 4 extremely high outliers, but the residuals were normally distributed following removal of these outliers. Treatment, week, batch, sex, and the type of pig were used as fixed effects, week was a repeated effect, and block within batch, and the plate on which the ELISA was performed, as random effects.

Physical scores were analysed using generalised linear mixed models (PROC GLIMMIX), with a Poisson distribution and a log link function. Treatment, week and batch were included as fixed effects, week as a repeated effect and block within batch as a random effect. When analysing tear staining scores, the eye (left or right) from which the score was taken was also included as a fixed effect. The damage recorded on the tongue and gum of the carcass was processed as binary data and analysed using GLIMMIX with a binary distribution and a logit link function for comparison between all treatments, and Chi-square to compare between pigs with wood and a rubber toy.

3. Results

3.1 Enrichment consumption

There was an effect of wood species on the consumption of the wooden posts. The reduction in length and weight was greater in Spruce than Larch and Beech (Table 2), as was the variation in dimension at the same position higher in Spruce than Larch and Beech (Table 2). No post was replaced in Larch and Beech pens, but only 2 out of 10 Spruce pens did not have posts replaced (average length of spruce post upon replacement was 84.62 ± 2.79 cm, and the

Table 2. Measurements taken on the wood species used in the study. Data are presented as least squares means ± SEM for moisture and hardness. Length and weight reduction and dimension variation since the preceding measurement were log-transformed for analysis, and with the raw LSMeans indicated in the brackets. Different letters indicate significant differences after Tukey-Kramer adjustment.

	Wood species			*F*-value	*P*-value
	Spruce	Larch	Beech		
Length reduction (mm/day)	1.09 ± 0.05 (3.53)[a]	0.59 ± 0.04 (-0.08)[b]	0.60 ± 0.04 (-0.07)[b]	33.3	< 0.001
Weight reduction (g/day)	3.57 ± 0.06 (22.05)[a]	3.15 ± 0.08 (3.91)[b]	3.03 ± 0.08 (1.10)[b]	16.83	< 0.001
Dimension variation (mm)	2.79 ± 0.10 (30.36)[a]	1.38 ± 0.12 (4.97)[b]	1.09 ± 0.12 (3.39)[b]	74.44	< 0.001
Moisture (%)	31.36 ± 0.89[a]	26.40 ± 1.02[b]	26.79 ± 1.02[b]	8.74	< 0.01
Hardness (Shore D scale)	27.92 ± 0.70[a]	41.85 ± 1.15[b]	46.23 ± 1.15[c]	1.49	< 0.001

average frequency of replacement for these posts was 5.53 ± 0.45 d). Spruce also had the highest moisture content and was the softest of the three wood species (Table 2). The interaction between week and treatment was only significant for spruce; weeks 7 and 8 had the highest weight reduction compared to weeks 1-4 ($P < 0.001$). The average consumption of the rubber toy was 5.34 ± 0.45 g/day.

3.2 Behaviour

3.2.1 Enrichment interaction

At the pen level, the average duration of interaction with the enrichment was higher when pigs had the Rubber toy or Spruce ($P < 0.01$, Figure 2A). There was a tendency for pigs to interact with the enrichment more during week 2 compared to week 4 ($P = 0.07$).

When analysed at the individual level, pigs interacted with the Rubber toy and Spruce more than Larch and Beech, both in terms of total duration ($P < 0.001$, Figure 2B), and average bout length ($P < 0.001$, Figure 2C). Kendall’s coefficient of concordance comparing pigs’ behaviour over different observation sessions was only significant for Beech ($W = 0.27$, $P < 0.01$) and Larch ($W = 0.25$, $P < 0.05$), and not for Spruce or Rubber toy, suggesting that there was a greater consistency in the amount of interaction that each pig had with the enrichment in pens with Beech and Larch. No sex difference was found in enrichment use, nor was there an effect of pig ‘type’ among the focal pigs.

During each observation session, about half of the pigs in the pen interacted with the enrichment (48.58 ± 2.37 %), but there was no difference between treatments (Figure 3A); moreover, a higher

Figure2

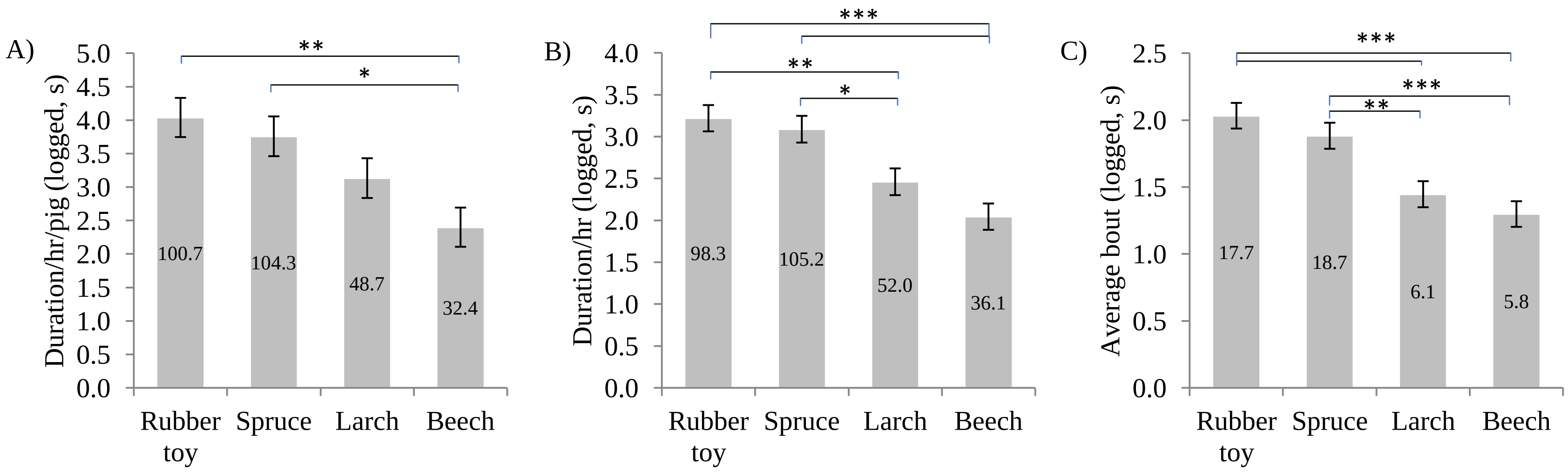

Figure 2. Average duration (logged) of interaction with the enrichment item between treatments (LSM of the original data as indicated on each bar). **A)** Total duration at pen level; duration was averaged between 2 days of observations per pen per pig ($F_{(3, 33.6)} = 6.19$), **B)** Total duration at individual level, duration was averaged between 2 days ($F_{(3, 257)} = 12.36$), and **C)** Bout lengths ($F_{(3, 254)} = 13.33$). Significant differences after the Tukey-Kramer adjustment are indicated by * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

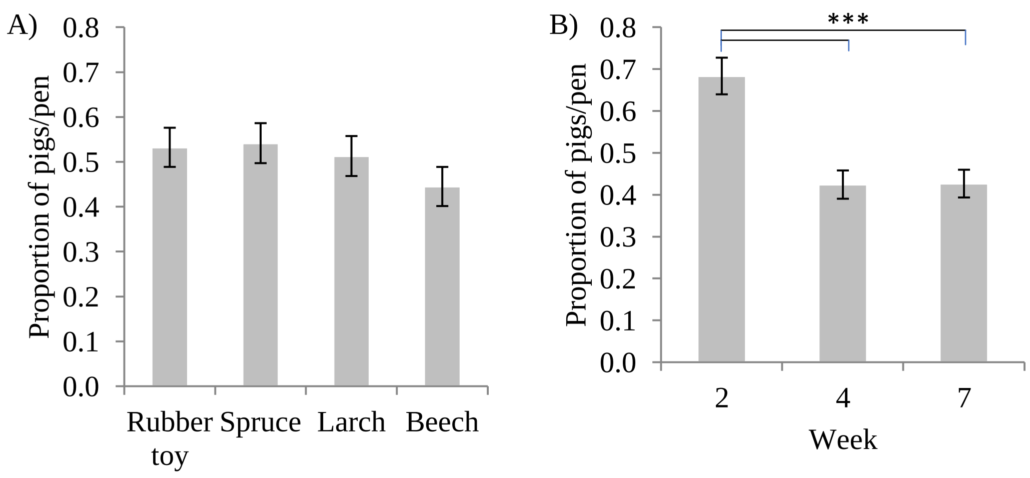

Figure 3. Proportion of pigs in a pen that interacted with the enrichment across **A)** Different treatments and **B)** Experimental weeks, Significant differences after the Tukey-Kramer adjustment are indicated by *** $P < 0.001$.

proportion of pigs in the pen interacted with the enrichment in week 2 compared to week 4 and 7 (Figure 3B, $P < 0.001$). Only one out of ten Spruce pens had one or more pigs that did not interact with the enrichment at all during six recording sessions, whereas there were three in Rubber toy, and four each in the Larch and Beech pens.

3.2.2 Other behaviours

There was no difference between treatments in tail or ear biting behaviour, both of these behaviours combined together, or play behaviour. On average, more ear biting (19.37 ± 1.53 s/hr/pig) was recorded than tail biting (3.54 ± 0.33 s/hr/pig). Pigs with spruce had more frequent aggressive encounters when interacting with the enrichment compared to beech (1.80 ± 0.36 v's 0.52 ± 0.35, $F = 3.26_{(27.4,3)}$, $P < 0.05$). There was a positive correlation between enrichment use and tail and ear biting combined at the pen level ($r_p = 0.45$, $P < 0.001$). No difference in behaviours between the types of focal pigs was found.

3.3 Salivary cortisol

No difference was found in salivary cortisol concentrations between treatments, however “Avoid” pigs’ exhibited slightly higher salivary cortisol concentrations than “Approach” pigs (0.16 ± 0.02 v's 0.13 ± 0.02 μg/dL, $F = 3.24_{(111,2)}$, $P = 0.04$), with “Neutral” intermediate. The inter-assay CV based on the control samples was 3.0% and the intra-assay CV was 16.6%.

3.4 Physical scores

Pigs enriched with Spruce had higher tail lesions on the Hunter scale than Beech (Figure 4, $P < 0.05$), and similarly higher tail damage scores using the FareWellDock system (Figure 4, $P < 0.05$). However, there was no difference in the presence of blood on the tail. There was no difference in ear lesion scores and tear staining scores between any of the treatments.

3.5 Carcass data

The post-mortem tail lesion scores did not differ between treatments, and neither did the presence of possible damage recorded in the tongue and gum area on the carcasses. Chi-square analysis also showed no difference between pigs using wood or rubber toy in terms of the oral damage ($X^2_{(1,\, n\, =\, 280)} = 1.202$, $P = 0.27$, Figure 5).

4. Discussion

This study investigated whether pigs interacted differently with three different wood species or a non-organic rubber floor toy, and whether there were any effects on damaging behaviours, physical injuries, and salivary cortisol. Pigs interacted more with Spruce posts and the Rubber toy than Larch and Beech posts, but the Spruce enriched pigs had slightly higher tail lesion scores. No effect of enrichment type on cortisol concentration, ear lesion or tear staining scores was found, even though the overall enrichment use showed a positive correlation with damaging behaviours at the pen level. In the Spruce and Rubber toy enriched pens, individual pigs were not consistently high users over 6 recording sessions. Overall sex or pig type did not appear to affect enrichment use. The carcass inspection revealed no clear signs of damage to the mouth and gum that could

Figure4

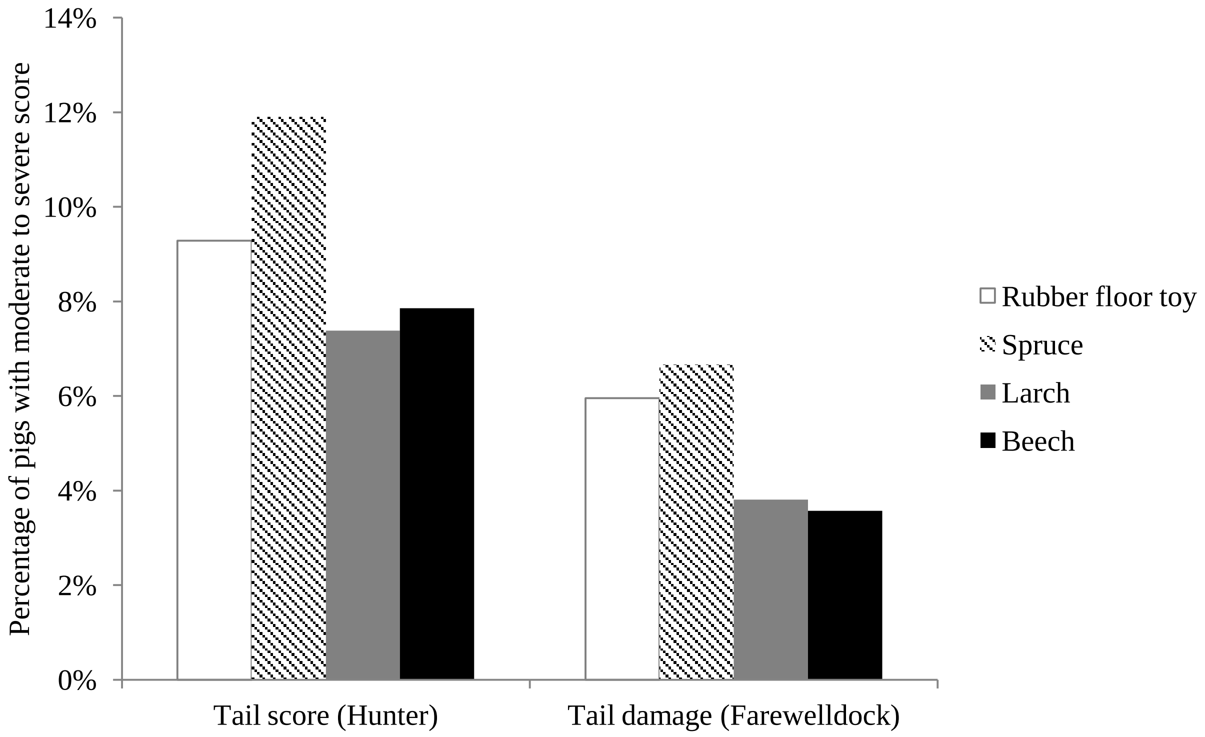

Figure 4. Percentage of pigs with moderate to severe tail lesion scores (score 2-3) in different enrichment treatments. Pigs with spruce had higher tail lesion scores ($P < 0.05$). Hunter tail lesion scale: 0-no damage, 1-mild, 2-moderate, 3-severe. Tail damage: 0-no lesion, 1-bite marks, 2-open wound, 3-swollen bite wounds.

Figure5

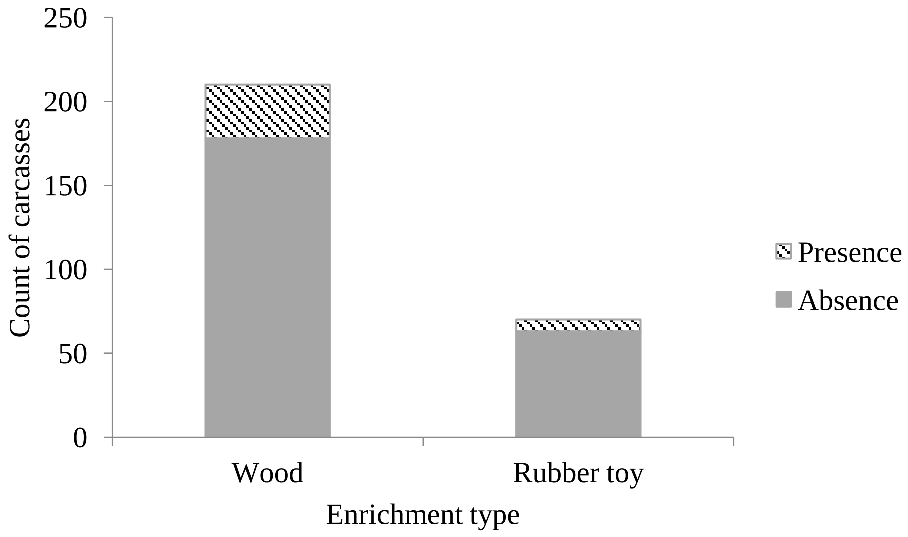

Figure 5. Presence or absence of damage to the tongue and gum area recorded on the carcasses. No difference between pigs with wood or rubber floor toy was found by Chi-square test ($X^2_{(1,\, n\, =\, 280)}$ = 1.202, P = 0.27).

be attributed to wood splinters, and therefore dried wood sourced from sawmills appeared to be safe to use as environmental enrichment for pigs.

In the current study, pigs spent a longer time interacting with the spruce post and the rubber floor toy compared to larch and beech posts. Within the wood species investigated, the longer time that pigs spent interacting with Spruce compared to the other species, was also reflected in the longest bouts of interaction. Moreover, spruce posts also had the highest weight loss per day compared to larch and beech, which agrees with our previous study (Chou et al., 2018), comparing spruce with larch, beech and Scots pine (*Pinus sylvestris L.*). Spruce was the softest wood, and this quality probably attracted more use from the pigs and led to depletion more quickly, and consequently a more frequent replacement rate. Being destructible and deformable are the qualities of enrichment preferred by pigs (Van de Weerd et al., 2003). Moreover, the frequent replacement and the higher reduction in length and variation in dimension from consumption likely led to more morphological changes and increased novelty due to replenishment, compared to the other wood types. This may mean use of spruce posts was more appealing over time compared to the other two types of wood (Chou et al., 2018).

Pigs interacted with the rubber floor toy at a similar level to the spruce post in the present study. Rubber materials are not considered more suitable as enrichment than organic ones (European Commission, 2016). Nevertheless, previous studies have also found that when provided as a point-source enrichment item, soft rubber items did not necessarily generate fewer interactions from pigs than organic items (Horback et al., 2016; Telkänranta et al., 2014), albeit they are not as attractive as loose materials (Scott et al., 2009; Van de Weerd et al., 2006). The rubber floor toy used in the current study is very easily accessed not only because it can be placed in the centre of the pen, but also because it is moveable and can therefore stimulate reciprocal actions between pigs. Although sometimes floor items can be soiled easily, the device used in the present study was designed so that there was minimal contact surface with the ground. When presented in this way, floor items can generate more frequent interactions than hanging organic items (Chou et al., 2019b).

A further aim of the study was to understand the variation within pens between individual pigs in terms of enrichment use and other behaviours. The analysis showed that the high use of spruce posts was not a result of a few consistent high users. This may also suggest that pigs interacted more equally among groups when the quality of the enrichment was more attractive, as they were observed to interact more with the spruce post and the rubber floor toy on average. A positive finding was that there was no difference in enrichment use between sexes or types of pigs that showed different responses to human approach, indicating again that a particular pig type did not dominate enrichment access or use. However, during each observation session only approximately half of the pigs in the pen interacted with the enrichment item in all treatments, and in some pens (even one Spruce pen) there were pigs that did not once use the enrichment during all 6 sessions. Larsen et al., (2019) compared pigs' use of pine posts with a previous study which used similar methodologies with small amounts (10 g/pig/day) of loose straw

(Jensen et al., 2015). These authors found that the highest usage of pine posts (22 s/hr/pig) in their study was only similar to straw use 3 to 8 hours after provision (15 s/hr/pig), when the straw was possibly already depleted. The authors concluded that provision of wood as enrichment at a 1:4.5 ratio may not be sufficient to satisfy pigs' exploratory needs. In the current study, Spruce attracted around 100 s/hr of interaction per pig, which was higher than in Larsen et al., (2019) and could be due to a different presentation and a smaller pen size (Apple and Craig, 1992). Nevertheless, this is still much lower than when 10 g/pig/day of straw was freshly provided (501 s/hr/pig, Jensen et al., 2015). Straw has commonly been regarded as the gold standard in enrichment provision for pigs (Studnitz et al., 2007; Van de Weerd et al., 2006), and the much lower interaction with the spruce post in the current study, than that with a minute amount of straw was provided, could indicate that wood is not as biologically relevant for pigs.

Furthermore, the proportion of pigs interacting with the enrichment decreased in all treatments over time, even though the consumption of the spruce post increased. This suggests that as the pigs matured, they were increasingly more capable of destructing the posts, without a higher rate of use. In fact, pigs provided with spruce had slightly higher tail lesion scores than other treatments, and the positive correlation between enrichment use and damaging behaviours showed that the enrichment provided in the current study did not prevent damaging behaviours. Indeed if environmental enrichment stimulates pigs' exploratory instinct, but fails to satisfy their behavioural need, it could potentially induce frustration and in turn generate more manipulative behaviours towards pen mates (van de Weerd and Ison, 2019). The spruce post might have stimulated pigs' appetitive behaviour to forage but was not enough to help them reach the consummatory phase, leading to the higher rate of biting in this treatment (Duncan, 1998). Nevertheless, the overall occurrence of damaging behaviours, especially tail biting, was quite low in this study. This may however, be a result of tail docking, as Chou et al., (2019a) found that a spruce post and a rubber floor toy were ineffective in preventing tail biting in undocked pigs at a 1:14 ratio.

There was no difference in salivary cortisol concentrations observed between treatments in the current study, which may suggest the organic enrichment and the non-organic counterpart did not contribute to alterations in different physiological responses that affect cortisol homeostasis. Compared to other studies which adopted a similar method of saliva collection, Giuliotti et al., (2019) found that finishers enriched with only a metal chain had the similar salivary cortisol concentrations as pigs enriched with both wood and chain. Similarly, Casal et al., (2016) compared pigs housed in a barren or enriched (sawdust, hemp ropes and rubber balls) environment, and only found in the barren pigs higher hair cortisol and salivary Chromogranin A, but not salivary cortisol. Another possible explanation for not finding differences between treatments could be that simply varying the type of enrichment, when provided at a rate of one item per 7 pigs (or as in Giuliotti et al. (2019), 3 wood logs per 25 pigs) does not generate enough of a difference in environment to induce different physiological responses. Moreover, compared to previous studies which used a similar breed of finisher pigs at resembling ages, the pigs' salivary cortisol concentrations quantified in the current study appeared to be similar or lower (Bradshaw et al., 1996; Casal et al., 2016; Coutellier et al., 2007; de Jong et al., 2000; Escribano et al., 2015; Nzolo, 2014; Scollo et al., 2014). Even for the "Avoid" pigs, which had marginally higher salivary cortisol concentrations compared to the "Approach" pigs, the cortisol concentration was not outside the normal range compared to previous studies. Although this higher cortisol concentration in "Avoid" pigs may suggest that they might be slightly more aroused during sample collections than "Approach" ones, the different types of pigs were only defined by the latency to voluntarily approach the experimenter when taking the first saliva sample. It should be noted that no further behavioural tests or repeated measures were conducted to validate these categorisations (Boissy and Erhard, 2014).

Post-mortem inspection of the tongues and gums revealed no obvious ante-mortem oral damage was sustained in pigs which had any specific type of enrichment during the trial. To the best of our knowledge, this is the first attempt to conduct post-mortem examination on the oral cavity of finishing pigs. Due to a lack of knowledge on pigs' oral health in general, we attempted to record any visible damage. Some examples of the damage observed can be found in supplementary material II. Although there are concerns that dried wood can present a risk of splintering and consequent damage to pigs' health (European Commission, 2016), currently no evidence supports these concerns. The amount of oral damage recorded in the current study was not significantly higher in pigs with a specific wood species, or all wood species combined, compared to the rubber toy. This suggests that the damage observed could be caused by factors other than the enrichment materials provided, and common to all pens (e.g. oral manipulation of other pen fixtures). Another possible explanation is the damage was incurred post-mortem, during the carcass processing. Pigs are opportunistic omnivores by nature and do ingest a variety of organic substances during foraging (D'Eath and Turner, 2009; Held et al., 2009); as such, it is unlikely wooden materials would be unsafe for them, and the results are therefore unsurprising. Further toxicological studies should investigate whether there are other substances in some wood species that could be harmful to pigs.

5. Conclusions

Spruce posts and the rubber floor toy attracted more interaction from pigs more than larch and beech, although no difference in damaging behaviours and salivary cortisol concentration was found, and pigs with spruce had slightly higher tail lesion scores. The higher usage of spruce and the rubber toy was not attributable to consistent high users, but the overall duration of interaction was still quite low in comparison to previously reported data for small quantities of straw. No clear damage to the carcass was found caused by using wood; hence standardised dried wood appears to be safe as environmental enrichment for pigs. Based on the current results, the spruce post appears to be a safe and preferred wood species to be used as an enrichment item and so does the rubber floor toy. However, due to the low level of tail biting recorded and higher tail lesions in pigs with Spruce, further work is needed to assess the efficacy of using suitable point-source items along with other enrichment provision to prevent pigs from tail biting when the pigs' tails are not docked.

Conflict of interest statement

The authors declare no conflict of interest.

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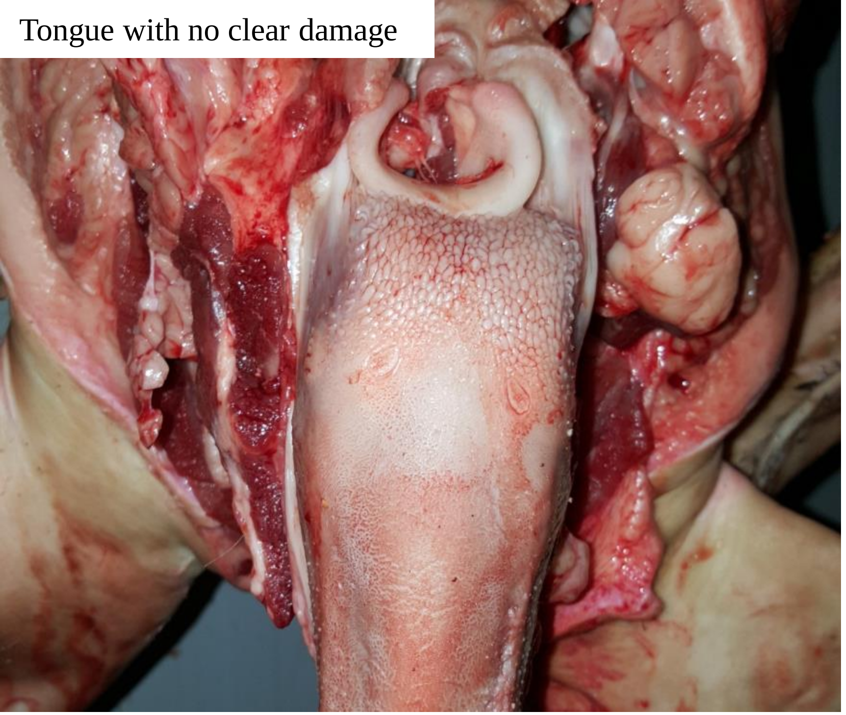
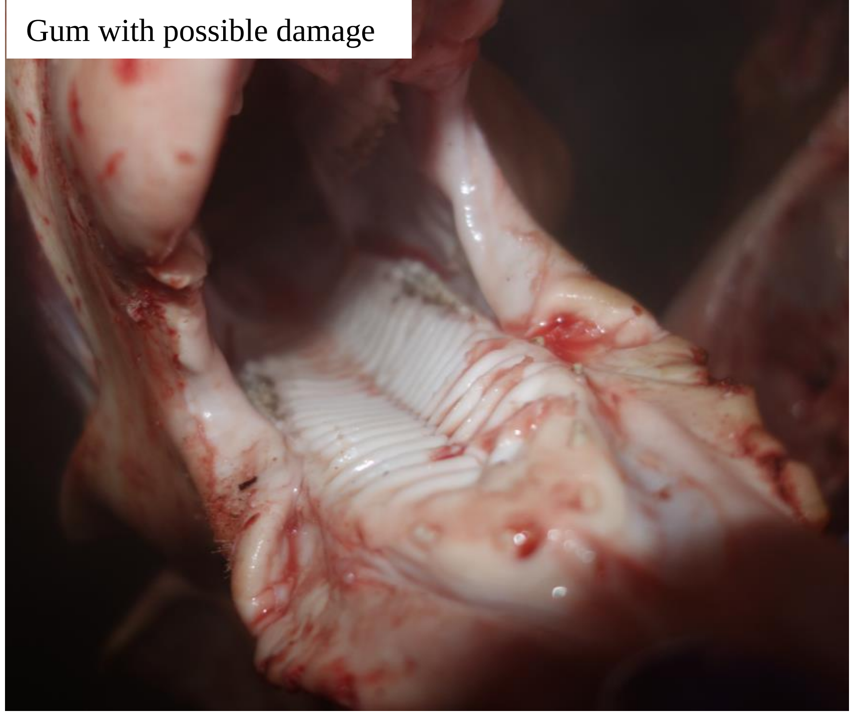
Supplementary material I. Room layout and blocking plan

EMPTY Pen 19			Beech BLOCK 4 **Pen 18**
Floor toy BLOCK 5 **Pen 21**	EMPTY Pen 20	EMPTY Pen 16	Floor toy BLOCK 4 **Pen 17**
Spruce BLOCK 5 **Pen 23**	EMPTY Pen 22	EMPTY Pen 14	Larch BLOCK 4 **Pen 15**
Beech BLOCK 5 **Pen 25**	Larch BLOCK 2 **Pen 24**	Beech BLOCK 3 **Pen 12**	Spruce BLOCK 4 **Pen 13**
Larch BLOCK 5 **Pen 27**	Beech BLOCK 2 **Pen 26**	Spruce BLOCK 3 **Pen 10**	EMPTY Pen 11
EMPTY Pen 29	EMPTY Pen 28	EMPTY Pen 8	Beech BLOCK 6 **Pen 9**
Control BLOCK 1 **Pen 31**	EMPTY Pen 30	EMPTY Pen 6	Spruce BLOCK 6 **Pen 7**
Beech BLOCK 1 **Pen 33**	Spruce BLOCK 2 **Pen 32**	Larch BLOCK 3 **Pen 4**	Floor toy BLOCK 6 **Pen 5**
Larch BLOCK 1 **Pen 35**	Floor toy BLOCK 2 **Pen 34**	Floor toy BLOCK 3 **Pen 2**	Larch BLOCK 6 **Pen 3**
Spruce BLOCK 1 **Pen 36**			Empty Pen 1

FEEDING STATION


Tongue with no clear damage


Gum with possible damage


Tongue with possible damage


Gum with no clear damage


Tongue with possible damage


Tongue with possible damage (suspected post-mortem)

Discussion of Chapter 4

This study was a continuation of the previous chapter (**Chapter 3**), which also compared different wood species used as enrichment for pigs. It further compared the wood species with a soft rubber floor toy. This addressed the first two objectives of this thesis, which is to identify the most suitable wood species, and to investigate if wood is better than the inorganic enrichment material selected. Similar to Chapter 3, spruce was again found to be the softest species, and it was consumed the quickest of all wood species. However, spruce also had the highest moisture content in this study, unlike in Chapter 3, when the level was similar to that of larch and beech. The difference may be due to the different type of wood dispenser. In the previous study (**Chapter 3**), the dispenser allowed the wood to be elevated from the ground, and the opening where the pigs could access the wooden post was small (0.2 m). However, in the current study, the lower end of the wood post touched the ground, and the length of the post that pigs could access was longer (around 0.35 m). This could have increased the moisture content, as pigs could interact with a greater surface of the post, and since pigs interacted with spruce most often, so it was exposed to a higher quantity of saliva.

When considering only the wood types, the interaction with, and the consumption of spruce, was the highest in both studies. The current study also found that the interaction bout length was the highest when pigs had spruce, suggesting spruce is the most preferred wood species. Nevertheless, the rubber floor toy attracted a similar pattern of interaction from pigs as spruce, both in terms of total interaction duration and bout length, which suggests that the floor toy may be more suitable enrichment than harder wood species. There was no effect of enrichment type in terms of tail or ear biting in both studies due to overall low occurrences, but still, in the current study, pigs with spruce had a slightly higher tail damage score than those with beech, whereas in Chapter 3 there was no difference. One of the reasons could be that spruce in the present study generated a higher level of interaction than it did in Chapter 3, probably due to both a different accessibility level due to the dispenser used, as well as the pig to enrichment ratio (1:25 in Chapter 3 and 1:7 in the current study). However, it may not have satisfied the pigs' exploratory needs, and then their attention became re-directed towards the tails of other pigs. However, during the observation periods, no difference in tail biting behaviour was observed, and only a positive correlation between pen-level enrichment interaction and tail and ear biting was found. Since a low occurrence of tail biting was recorded, it is inconclusive whether any of the enrichment items compared was more effective than any others in reducing tail biting.

To supplement the behaviour observations and physical scores, salivary samples were taken as a physiological indicator of stress; however, no difference was found between treatments. We were also able to conduct detailed carcass examination in the abattoir to investigate the presence and severity of oral lesions (this was unachievable due to a much larger-scale abattoir used by the commercial farm in Chapter 3). We found no clear evidence that using any species of wood could have caused damage to pig's tongue and gum.

The next step (**Chapter 5**) is to use the preferred enrichment items identified over these two studies, the spruce post and the rubber floor toy, to rear undocked pigs under conditions that are similar to Irish commercial farms. A dietary strategy of using higher fibre level was also investigated, along with the type of enrichment provision.

Corrections: The diet given to the finishing pigs in this study has the net energy 9.56 MJ/kg, 15.97% protein and 4.26% crude fibre).

Chapter 5 Can increased dietary fibre level and a single enrichment device reduce the risk of tail biting in undocked pigs on fully slatted systems?

This chapter is the manuscript submitted to *animal* on 29 May 2019: Chou J.-Y., O'Driscoll K., Sandercock D.A. and D'Eath R.B., Can increased dietary fibre level and a single enrichment device reduce the risk of tail biting in undocked pigs on fully slatted systems? 2019. This is a revision after reviewers' comments and may appear in a revised form subsequent to peer review and editorial input by Cambridge University Press and the Animal Consortium. Please find further information on the journal at https://www.cambridge.org/core/journals/animal.

This chapter had been previously presented as a poster in: **Chou, J.-Y.**, D'Eath, R.B., Sandercock, D.A. and O'Driscoll, K. 2019. Can dietary fibre level and a single enrichment type reduce the risk of tail biting in undocked pigs. Proceedings of the 11th European Symposium on Porcine Health Management (ESPHM), 22-24 May, Utrecht, the Netherlands.

Introduction to Chapter 5

After identifying the spruce post and the rubber floor toy as being preferred point-source enrichment items in Chapter 3 and 4, , these were used in this study as the enrichment treatments, combined with the investigation of dietary fibre. Altering the composition of the diet is considered to cause less disruption to current production practices and more cost-beneficial than changes in infrastructure, and additional provision of environmental enrichment. As the main objective of the thesis is to look for feasible strategies that are compatible with the fully-slatted housing systems which currently predominate in Ireland, only one point-source enrichment item per group was provided (at a ratio of 1:14), along with one of two dietary treatments (weaner 3.7% or 5.3% and finisher 5.9% or 11.6% of crude fibre) in the diet. Undocked, intact-tailed pigs were used for the first time in the thesis. The study was designed in a way to mimic current commercial practices in Ireland, in order to understand the likely outcome if tail docking were to cease.

I contributed to the experimental design, feed formulation, data collection, statistical analysis, data presentation, original draft preparation and review and editing of the manuscript. Technicians David Clarke and Oliver Clear from Teagasc, Moorepark, and intern students Alexandra Courty and Marleen van de Heide assisted in data collection. Dr Edgar Garcia Manzanilla provided advice on feed formulation.

This study was approved by the Teagasc Animal Ethics Committee screening (TAEC124/2016) and the sample size calculation was estimated using G*Power 3.1.9 (Faul et al., 2007) with the effect size of 0.4, α err probability of 0.05, power of 0.8 and a 2 × 2 × 2 factorial design.

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Can increased dietary fibre level and a single enrichment device reduce the risk of tail biting in undocked pigs on fully slatted systems?

--Manuscript Draft--

Manuscript Number:	ANIMAL-19-40580R1
Full Title:	Can increased dietary fibre level and a single enrichment device reduce the risk of tail biting in undocked pigs on fully slatted systems?
Short Title:	Can high fibre and enrichment reduce tail biting?
Article Type:	Research Article
Section/Category:	4a. Welfare and Behaviour
Keywords:	High fibre diet; wood; rubber floor toy; weaner and grower pigs; damaging behaviour
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Manuscript Region of Origin:	IRELAND
Abstract:	Tail docking has been banned in the EU as a routine practice to control tail biting in pig production since 2003. However, solutions are still needed to prevent tail biting in undocked pigs in conventional housing systems. This study evaluated the effectiveness of combined dietary and enrichment strategies to manage tail biting in pigs with intact tails. The experiment used a 2 x 2 x 2 design (N = 48 pens): a high (weaner 5.3% and finisher 11.6% of crude fibre; N = 24) or standard (weaner 3.7% and finisher 5.9% of crude fibre; N = 24) fibre diet; either a spruce wooden post (supplied in a fixed Funbar® dispenser on one side of the pen, N = 24) or a rubber floor toy (N = 24) as enrichment device in the weaner stage; the same (N = 24) /alternate (N = 24) enrichment given in the finisher stage. Six hundred and seventy-two pigs were assigned to 48 pens of 14 pigs and followed from weaning until slaughter. Individual tail lesion scores (0-3 scale on both tail damage and the freshness of blood) and direct behaviour observation at a pen level were the main measures for assessment. During the experiments 26 tail biting outbreaks were recorded, and 194 pig removals from their home pens were made temporarily for severe tail treatment. Results showed that pigs fed with the high fibre diet had slightly worse tail damage score than those with the standard fibre diet ($P < 0.05$) and performed more tail biting ($P < 0.05$). Pigs which had the floor toy as weaners and wood as finishers recorded fewer tail lesions in the finisher stage than their counterparts ($P < 0.05$). Pigs receiving the floor toy as enrichment interacted with the enrichment more frequently overall ($P < 0.001$) and performed fewer harmful behaviours in the weaner stage ($P < 0.05$). The study has shown that simply altering the fibre level in pigs' diet and providing a single enrichment device was insufficient to keep tail biting at a manageable level in undocked pigs on fully slatted floors. Higher fibre in the diet in a relatively barren environment did not help reduce tail biting or tail lesions, and although a difference was found between enrichment treatments, neither was effective enough to control tail biting in undocked pigs.

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Can increased dietary fibre level and a single enrichment device reduce the risk of tail biting in undocked pigs on fully slatted systems?

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Short title: Can high fibre and enrichment reduce tail biting?

Abstract

Tail docking has been banned in the EU as a routine practice to control tail biting in pig production since 2003. However, solutions are still needed to prevent tail biting in undocked pigs in conventional housing systems. This study evaluated the effectiveness of combined dietary and enrichment strategies to manage tail biting in pigs with intact tails. The experiment used a 2 x 2 x 2 design (N = 48 pens): a high (weaner 5.3% and finisher 11.6% of crude fibre; N = 24) or standard (weaner 3.7% and finisher 5.9% of crude fibre; N = 24) fibre diet; either a spruce wooden post (supplied in a fixed Funbar® dispenser on one side of the pen, N = 24) or a rubber floor toy (N = 24) as enrichment device in the weaner stage; the same (N = 24) /alternate (N = 24) enrichment given in the finisher stage. Six hundred and seventy-two pigs were assigned to 48 pens of 14 pigs and followed from weaning until slaughter. Individual tail lesion scores (0-3 scale on both tail damage and the freshness of blood) and direct behaviour observation at a pen level were the main measures for assessment. During the experiments 26 tail biting outbreaks were recorded, and 194 pig removals from their home pens were made temporarily for severe tail treatment. Results showed that pigs fed with the high fibre diet had slightly worse tail damage score than those with the standard fibre diet ($P < 0.05$) and performed more tail biting ($P < 0.05$). Pigs which had the floor toy as weaners and wood as finishers recorded fewer tail lesions in the finisher stage than their counterparts ($P < 0.05$). Pigs receiving the floor toy as enrichment interacted with the enrichment more frequently overall ($P < 0.001$) and performed fewer harmful behaviours in the weaner stage ($P < 0.05$). The study has shown that simply altering the fibre level in pigs' diet and providing a single enrichment device was insufficient to keep tail biting at a manageable level in undocked pigs on fully slatted floors. Higher fibre in the diet in a relatively barren environment did not help reduce tail biting or tail lesions, and although a difference was found between enrichment treatments, neither was effective enough to control tail biting in undocked pigs.

Keywords

High fibre diet, wood, rubber floor toy, weaner and grower pigs, damaging behaviour

Implications

Tail biting is a damaging behaviour in pigs that can be difficult to control, especially when pigs with undocked tails are reared in a housing system with slatted floors (and therefore no loose material can be easily provided). This study has shown that simply increasing the dietary fibre and providing a single enrichment item for pigs to manipulate is not sufficient to control severe tail biting, and frequent removals and treatments of tail bitten pigs were required. More complex enrichment strategies are therefore needed.

Introduction

EU Commission Directive 2001/93/EC (European Commission, 2003) laid down minimum standards for pig welfare, stating that tail docking was banned as a routine practice to control tail biting. However, according to a recent survey, among all EU countries approximately 77% of pigs are still tail docked (De Briyne et al., 2018). One of the main challenges identified was fear by pig producers of the consequences of tail biting if docking is not performed. Lahrmann et al. (2017) recorded higher prevalence of tail lesions among undocked than docked pigs when housed on conventional partly-slatted floor systems. On the other hand, using tail docking to manage tail biting potentially masks the underlying issues caused by insufficiencies in the production system (Edwards and Bennett, 2014; D’Eath et al., 2016).

Studies have suggested that the floor type (solid or slatted) is an important risk factor for tail biting; slatted floors are associated with a higher prevalence of tail biting (Moinard et al., 2003; EFSA, 2007). However, floor type is often confounded with other factors such as enrichment provision. Although the absence of straw and other bedding material has been identified as the most vital factor influencing tail biting prevalence (Schrøder-Petersen and Simonsen, 2001; Moinard et al., 2003; Taylor et al., 2010), on fully-slatted floors loose material hinders slurry management (D'Eath et al., 2014), so cannot be liberally used. Therefore, tail biting is difficult to manage in fully-slatted systems, which are commonly utilised in the EU (EFSA, 2005), without drastic changes that could have negative economic implications for the producers (D'Eath et al., 2016). This is also the main reason why there is still a high prevalence of tail docking, since economically feasible solutions are lacking.

Wood was listed as a suboptimal organic enrichment material in the European Commission recommendation (2016). The species of wood can affect rate of interaction; studies have shown that spruce (*Picea sitchensis*) as a softer species could attract more interactions from the pigs compared to other species that are harder (Chou et al., 2018, 2019a). However, although wood is an organic material listed in the EC recommendation (2016), it does not always generate more interaction from pigs than inorganic enrichment materials (Horback et al., 2016), and the presentation of an enrichment material can also influence its attractiveness (Barbari et al., 2017). Nevertheless, Telkänranta et al. (2014) showed that provision of branches of fresh cut wood reduced tail lesions in undocked pigs, compared to polyethene pipes and chains. Other forms of inorganic point-source enrichment materials have been tried on undocked pigs but were less effective in preventing tail biting (van de Weerd et al., 2006; Zonderland et al., 2008). Therefore, in the current study, an inorganic rubber enrichment was used as the control and compared with a spruce post.

Studies have showed that modification of diet can also have an effect on tail biting behaviour in pigs (Taylor et al., 2010), but only in terms of protein and minerals.

The effect of dietary fibre on pig behaviour has mainly been researched in relation to satiety among restricted-fed sows (de Leeuw et al., 2008), and the authors suggested that the fibre source with a high bulkiness could reduce oral manipulation behaviours immediately post-feeding, and highly fermentable fibre could further reduce general activity level by offering a prolonged satiety. In growing pigs, Kallabis and Kaufmann (2012) found that fattening pigs fed higher dietary fibre tended to have fewer meals per day and a lower daily feed intake but spent more time feeding and ate more slowly. Although the authors recognised the effect of high dietary fibre on improving satiety and inferred a likely reduction in oral manipulative behaviours, the evidence is still lacking in the literature.

This present study combined the use of a point-source enrichment material that is compatible with the slatted systems, with a dietary modification of increased fibre content to evaluate their effectiveness at controlling tail biting in undocked pigs. Soybean hulls with moderate fermentability, water-holding capacity and bulkiness (de Leeuw et al., 2008) were used as the main ingredient to increase fibre level, and either a spruce post or a rubber floor toy provided as enrichment. It was hypothesised that groups with the higher fibre diet, and the wooden post would have a lower occurrence of tail biting behaviour and lesions.

Material and methods

Animals and housing

A total of 672 piglets (Landrace × Large White) were farrowed in the experimental unit in Teagasc, Moorepark, Ireland, over two batches at an interval of three weeks. Piglets were teeth-clipped after farrowing, and their tails left undocked. No castration of male pigs was carried out. A conventional farrowing pen system (2.4

m × 1.8 m) was used. Each pen contained a metal farrowing crate (2.2 m × 0.6 m) for the sow, and a floor heating plate (1.6 m × 0.4 m) for the piglets. The floor area was fully-slatted except the heating plate, and the piglets had access to a nipple drinker and a rope provided to the sow as enrichment. The temperature during lactation was maintained at around 24°C.

At weaning (4 weeks post-farrowing), all piglets were individually tagged, and weighed, and piglets lighter than 5 kg (17 in each batch) were not included further in the experiment. Remaining piglets were then randomly blocked into one of 6 blocks (three per farrowing batch), with each of the 8 treatments represented once in each block, forming 48 pens in total (14 pigs per pen and 6 pens per treatment). Pigs were balanced for weight between pens, and also for sex (half male/female) and litter mates within pens as far as practically possible. The average weaning weight was 7.60 ± 1.26 kg. Pens within the same block for each treatment were located along the same corridor in the weaner and finisher housing. Throughout the production cycle, pigs were fed *ad libitum* by a single-spaced wet-dry feeder with dry pelleted feed (one nipple drinker inside the feeder), with another nipple drinker separate to the feeder (i.e. two drinkers in the pen in total). Weaner pens were dimensioned 2.4 m × 2.6 m with a fully-slatted plastic floor. The temperature was maintained by automatic heating and negative pressure mechanical ventilation at 28°C in the weaner house immediately post-weaning. It was lowered by 2°C every 2 weeks thereafter. Seven weeks post-weaning, the pigs were transferred to the finisher facility (concrete slatted floors, dimensions of 4 m × 2.4 m). In the finisher house the temperature was maintained at 20°C with the same ventilation system as in the weaner house, only without heating. Rooms were equipped with windows which enable the pigs to be in contact with natural light. Artificial lighting (150 lux in weaner house and 130 lux in the finisher house) was provided for 10-12 hours/day to ensure sufficient lighting to retain a normal circadian rhythm.

Experimental design

The study used a 2 × 2 × 2 factorial design. This was based on the type of enrichment in the weaner stage (wood or toy), finisher stage (wood or toy), and the level of fibre (standard or high) in the diet. Each treatment was replicated 6 times (N = 48; i.e. 3 times per batch).

Enrichment treatments

At weaning, half of the pens were each provided with a rubber floor toy (Easyfix Luna 117®, Easyfix, Ballinasloe, Ireland), while the other half were each given a dried spruce squared wooden post. At the start of the experiment, the wooden posts were 1.100 ± 0.001 m in length, 1.342 ± 0.101 kg in weight and 0.231 ± 0.002 m in perimeter (mean ± s.d.), and they were provided in a plastic dispenser (Funbar®, Jetwash Ltd., Carrigallen, Ireland; weaner 0.04 m and finisher 0.07 m in length, Figure 1) fixed diagonally on the wall, angled at around 45°, the optimal angle based on a previous pilot study. In this pilot study, a higher frequency of interaction from the pigs was recorded with the 45° angled dispenser compared to ones vertically placed. The lower end of the dispenser was at 0.03 m above the floor, and the upper and lower end of the wooden post was exposed for pigs' use. Upon transferring to the finisher house, half of the pens continued with the same type of enrichment and half of the pens alternated to the other type.

Dietary treatments

The weaners were given a commercial starter diet (Startrite 88, Provimi, Ireland) in the week immediately post-weaning, followed by a standard link diet (home-milled) for two weeks. The standard link diet is rich in lysine and amino acids, and this is a common practice on Irish farms to ensure the diets meet the nutritional requirements for pigs post-weaning. Afterwards, the standard fibre treatment continued to be fed with a diet containing a wheat, soybean and barley based formula, typical of diet used in Irish systems (Table 1). In the high fibre diets, the addition of vegetable oil was used to match the energy density, whereas the carbohydrate ingredients such as maize and barley were mostly substituted with soybean hulls as the main fibre source (with some inclusion of wheat bran in the weaner diet). These steps were taken in order to keep the energy, protein, lysine and mineral level as closely similar as possible between the dietary treatments, while increasing the fibre level in the high fibre diet. The finishers' diets were formulated so that the high fibre diet was almost double the crude fibre of the standard diet, and around 1.5 times in the weaners' diets. All diets were pelleted.

Measurements

Physical scores

Tail and ear lesion scores were recorded by one experimenter for each individual pig in week 2 post-weaning and fortnightly thereafter until slaughter. Tail lesions were scored based on the severity of damage, using a scoring system adapted from the FareWellDock project (Chou et al., 2019c with a visual guide; 'Damage': 0: intact, 1: bite marks, 2 open wound, 3: swollen bite wound). The freshness of blood present was also scored ('Blood': 0: no blood, 1: dry blood/black scar, 2: older red blood, 3: fresh blood). If tails were amputated and shortened, a tail amputation score was given based on an estimated length of amputation (0: no amputation, 1: remaining tail longer than 50% of original length, 2: remaining tail shorter than 50% of original length but longer than 3-5 cm which was the minimum length if tail docking was practiced, 3: remaining tail shorter than 3-5 cm). Ear lesions were scored on a 0-4 scale described in Chou et al. (2018) (0: undamaged, 1: superficial scratches, 2: evidence of recent bleeding, 3: bloody and red, 4: part of ear missing).

Behaviour observations

Behaviour observations were conducted by direct behaviour sampling continuously for 5 minutes at a pen level, based on a predefined ethogram (Table 3). The observations were carried out by one single observer on each pen on two days every other week from week 4 post-weaning. On each day there was one session in the morning between 10:00 h - 13:00 h and another in the afternoon between 15:00 h - 18:00 h (i.e. 4 recordings per pen per week).

Growth measures

Individual weights were measured at weaning, when transferring to the finisher house and two days before slaughter. Feed intake was recorded daily by a computerised automatic recording system (BigFarmNet, Big Dutchman, Vechta, Germany) at the pen level. Cold carcass weights were obtained from the slaughterhouse report.

Enrichment consumption

To compare consumption rate of the enrichment, the length and weight of the wooden posts were recorded before the start of the experiment, and subsequently every two weeks. The rubber floor toys were also weighed beforehand and every two weeks thereafter.

Tail biting outbreak intervention

Due to the high risk of tail biting outbreaks occurring, the ethical approval for the study mandated that a defined outbreak intervention protocol was developed to ensure that pig welfare was protected. An outbreak intervention protocol detailed in Chou et al. (2019c) was developed, which involved either 1) removing victims, 2) removing biters or 3) adding additional enrichment (ropes). The selection of each intervention protocol to be used was carried out using a pre-defined randomisation schedule. Chou et al. (2019c) found that there was no difference in the effectiveness of the three intervention strategies, and as they were randomised across treatments, we consider that the type of intervention applied to each pen did not impact upon the outcomes of the current study.

All pens were routinely checked for tail biting incidents at least three times per day by the experimenter and twice daily by the farm staff. Antibiotics (by cutaneous spray Alamycin® Aerosol, Norbrook, or by subcutaneous injection of Norocillin®, Norbrook) and analgesics (Loxicom®, Norbrook) were administered when pigs' tails were swollen with signs of infection. Pigs were removed temporarily for tail treatment whenever necessary for ethical reasons.

Statistical analysis of results

Data were analysed using SAS Base 9.4 (SAS Institute Inc., Cary, NC, USA). Chi-square was used to test if the likelihood of having a tail biting outbreak was greater in any treatment. For lesion scores, in order to account for the repeated scorings and the random effects, generalised linear mixed model was used to analyse all physical scores (Proc Glimmix), with Poisson distribution and a log link function. The model included fixed effects of replicate, week, sex, enrichment and diet treatments, and the interactions between treatments, with block as the random effect. The subject used in the model was individual pig nested within pen. The best-fit model was determined by step-wise removal of fixed effects until all effects in the model had at least a *P*-value of less than 0.2. The data in the weaner and finisher stage were initially analysed separately, then also combined. Only the enrichment treatment in the weaner stage was included as a fixed effect for the weaner data, while for the finisher data, enrichment in both stages and their interactions were used. This was conducted since the treatment during the finisher stage would not account for the outcome in the weaner stage. When weaner and finisher data were combined, enrichment treatment at the time of the recording was used. Week was always included as the repeated effect. The damage and the blood score of the tails were analysed separately and also together, as one general tail score. The graphical presentation of the lesion scores was the proportion of each score for a treatment.

Proc Glimmix was also used to analyse the number of pigs per pen that were removed and injected during the course of the experiment, including replicates, enrichment and diet treatments, and all interactions as fixed effects, and block as random effect (N = 48).

The Mixed procedure was used to analyse continuous data such as behaviours, weight, feed intake and enrichment consumption. All data were checked for residual normality. Non-normally distributed data were transformed using square root, which improved normality of residuals. Because removal of sick or injured pigs could reduce group sizes, behaviours were analysed as frequency per pig per minute. Similar to the physical scores, the behavioural data in the two growth stages were analysed both separately and combined with the same fixed effects. The best-fit model was determined by step-wise removal of fixed effects comparing between Akaike's Information Criterion (AIC), Corrected Akaike's Information Criterion (AICC) and Sawa Bayesian Information Criterion (BIC, all criteria are better if smaller). The data collected at different times of day and on different days of the same week were averaged. All behaviours combined and all harmful behaviours (tail biting, ear biting, biting other parts of the body and belly-nosing) were analysed additional to the individual behaviours. Biting, rooting and other contact with the enrichment were combined to be analysed as an overall interaction with the enrichment. The repeated effect of week and random effect of block was used. The unit for analyses was pen (N = 48).

Average daily gain (ADG) and average daily feed intake (ADFI) were analysed separately in the weaner and finisher stages and also together as an overall ADG and ADFI for the same reason mentioned above. Replicate, sex, enrichment in the weaner stage and the dietary treatment were included as the fixed effects for the weaner ADG and ADFI. The finisher ADG, ADFI and carcass weight further included enrichment treatments in both stages and all treatment interactions as fixed effects. The random effect of block was also included.

Enrichment consumption, of both the wooden posts and the floor toys, was analysed as weight loss (kg) per day per pig. Replicate, week and treatments were included as fixed effects; week was used as the repeated effect while block as the random effect. All data except the lesion scores were presented hereafter as mean ± s.e..

Results

During the course of the experiment, 26 tail biting events reached the criteria for a tail biting outbreak (out of which four pens had repeated outbreaks), but the likelihood of having an outbreak did not differ between treatments (*P* > 0.1, Table 2). Nine pigs were permanently removed from the experiment due to experiencing a severe tail lesion. In total, 161 pigs had tail wounds that needed to be temporarily removed from their home pens for treatment (of which 20 pigs were removed twice, 5 pigs removed three times and 1 pig removed four times), and 58 pigs were removed as tail biters. These pigs were later reintroduced to the home pen with no more than 7 days of separation. An additional 52 pigs were treated with antibiotic injection in the home pen. Table 2 listed the number of pigs removed or injected due to severe tail biting from each treatment groups. At the end of the experiment, 66.9% of pigs had some level of tail amputation.

Pens which had the rubber floor toy during the weaner stage tended to have fewer pigs removed for treatment at some point (3.16 ± 0.38) than those with the spruce post (4.22 ± 0.43; $F = 3.58_{(1,43)}$, $P = 0.07$). Pens with pigs on the standard fibre diet also had fewer individuals on average removed (3.07 ± 0.37) than pigs on the high fibre diet (4.34 ± 0.44; $F = 5.09_{(1,43)}$, $P = 0.03$). Looking at the finisher stage alone, there was an effect of the interaction between enrichment and diet: pens receiving wood in the finisher stage with the standard fibre (standard-wood) had lower number of pigs removed or treated with antibiotic injections (0.44 ± 0.19, compared to standard-toy 1.67 ± 0.42 and high-wood 1.85 ± 0.43, $F = 10.42_{(1,41)}$, $P < 0.01$).

Physical scores

The overall tail lesions (damage + blood) did not differ between pigs receiving different dietary or enrichment treatments (*P* > 0.1). However, tail lesion scores recorded in the finisher stage tended to be higher when pigs received wood during the weaner stage (*P* = 0.08, Figure 2A and 2B). When the tail damage score was analysed independent of the blood score, pigs given the high fibre diet had a higher tail damage score during the finisher stage than the standard fibre group (*P* = 0.04, Figure 2C).

Ear lesion scores in the finisher stage were higher in pigs which had the floor toy as enrichment than those which had wood (*P* < 0.01, Figure 3). There was also an effect of the interaction between diet and enrichment used in the weaner stage; pigs receiving the high fibre diet and wood as weaners had the highest ear lesion scores recorded during the finisher stage (*P* = 0.03).

Behaviour

Overall, tail biting was more frequently observed in the high fibre than the standard fibre pigs (*P* < 0.05, Table 4). However, this was only significant in the weaner stage (*P* < 0.05) and not in the finisher stage (*P* > 0.05, Table 4). There was no effect of enrichment on all harmful behaviours across stages (*P* > 0.05), but there was in the weaner stage, as was an effect of dietary fibre level (*P* < 0.05, Table 4).

The overall level of interaction with the enrichment was affected by enrichment treatment. Pigs had more overall interactions with the rubber floor toy than wood (*P* < 0.001, Table 4). The same effect was found in the two stages separately (Table 4). Pigs with the rubber floor toy had a higher frequency of all behaviours combined than pigs with wood (0.15 ± 0.02 v’s 0.12 ± 0.02; $F = 21.29_{(1,108)}$, *P* < 0.001).

Pigs receiving the standard diet performed more aggressive behaviours near the feeder than the high fibre treatment (0.019 ± 0.002 v's 0.012 ± 0.002; $F = 7.26_{(1,52)}$, $P < 0.01$). No effect was found regarding ear biting or other harmful behaviours individually ($P > 0.05$), and neither was there difference in play behaviours between treatments ($P > 0.05$).

There was an effect of time (week) on most behaviours, with a declining trend in frequency of observation as the pigs grow older, except for the interaction with the enrichment (Figure 4A-C).

Growth

Pigs fed the standard diet had a higher average daily gain (ADG) in the finisher stage than pigs fed with the high fibre diet (1.09 ± 0.01 kg v's 1.06 ± 0.01 kg; $F = 5.55_{(1,641)}$, $P < 0.05$). There was no effect of diet on the weaner ADG ($P > 0.05$). Similar to the growth rate in the finisher stage, the standard diet (74.24 ± 0.70 kg) contributed to a heavier carcass weight than the high fibre diet (72.48 ± 0.71 kg; $F = 6.6_{(1,637)}$, $P < 0.05$). The average daily feed intake was also higher in pigs fed with the standard diet (1.81 ± 0.01 kg/pig/day) than with the high fibre diet (1.75 ± 0.01 kg/pig/day, $P < 0.01$).

Enrichment consumption

The rate of consumption of the wooden post and the floor toy did not differ between enrichment or dietary treatments (P > 0.1). Both enrichment items showed an increased rate of weight loss as pigs grew older.

Discussion

This study investigated the effectiveness of a single point-source enrichment, combined with a high or standard fibre diet in reducing tail biting behaviour and tail lesions in undocked pigs kept on fully-slatted floors. The outcome of the experiment is that none of the combined or individual treatments effectively contained tail biting at a manageable level in this study. A substantial quantity of pigs (161 out of 672) needed to be removed from their home pens either for tail treatments or for outbreak control measures. The high fibre diet did not reduce tail biting behaviour, nor tail lesions, and the benefits of the enrichment device type were marginal and specific to different growth stages of the pigs.

Contrary to the original hypothesis, pigs fed a higher fibre diet did not perform less tail biting, especially during the weaner stage, and more pigs were removed in pens with high fibre diet. Similar results were found with regard to the lesion scores, as pigs in the high fibre treatment had higher tail damage scores during the finisher stage. According to de Leeuw et al. (2008), the higher fibre content in the diet can help sows to be less restless and the high fermentability of soybean hulls which were used in the current study, should reduce activity levels for many hours after feeding, which was not the case in the current study. However, sows were usually restricted-fed, whereas in this study the pigs were fed *ad libitum*, so the effect of fibre may not be the same. A study by Bolhuis et al. (2008) showed that increased dietary fibre only had an effect on decreasing pigs' physical activity when housed in straw-bedded environment. They concluded that under barren housing conditions, pigs' activity level was more affected by the lack of rooting materials and therefore the inability to satiate their motivation to root, rather than the diet itself. In the present study, the effect of the high level of fibre in the diet was in the opposite direction. One reason for higher levels of tail-directed behaviours, and consequently tail lesions, could be that pigs' faeces were affected by the high fibre diet. Oliviero et al. (2009) found that sows fed with higher fibre diet had softer faeces and higher water consumption. Soft and liquid faeces could more easily attach to the hindquarter of the pigs, which could stimulate increased levels of exploration from other pen mates. Moreover, Kallabis and Kaufmann (2012) reported that pigs fed with a more fibrous diet tended to have longer feeding bouts. In the context of the current experiment, where pigs were housed on slatted floors with limited environmental enrichment and a single-spaced feeder (which are known risk factors for tail biting; Kallio et al., 2018), longer feeding bouts might have increased the likelihood of tail biting incidence. The difference in energy between the standard and high fibre diets was greater in the finisher stage (Table 1), and a study suggested a link between a low energy diet and a higher risk of tail biting by showing that these pigs slightly preferred to chew on blood-soaked ropes than pigs fed with a control diet (McIntyre and Edwards, 2002). Similar to the tail biting results, pigs fed the high fibre diet performed more harmful behaviours combined than those fed the standard diet in the weaner stage.

However, overall pigs fed with the high fibre diet had fewer aggressive encounters at the feeder. One of the advantages of a higher fibre content in the diet is a reduction in the motivation to feed, and it can contribute to fewer meals per day (Meunier-Salaun et al., 2001). Although this might have reduced the competition for feed, another consequence could be that the high fibre might also prolong time spent at each meal, which would increase rather than reduce competition. The feed intake was indeed lower in pigs fed the high fibre diet in this study, but it should also be noted that although the primary difference between the standard and high fibre diet was the level of fibre content, the ingredients used in each diet differed slightly (e.g. a higher percentage of vegetable oil in high fibre diet, Table 1). The different composition of diets could influence their taste and palatability and therefore alter pigs' feeding behaviours. More detailed recordings of pigs' feeding behaviour are needed to further investigate the link between high dietary fibre and damaging behaviours. Higher fibre also contributed to a lower average daily gain, similar to what (Kallabis and Kaufmann, 2012) found. The difference in weight gain was only significant in the finishers possibly due to the fact that weaners in the current study had standardised starter and link diet for a total of 3 weeks post-weaning and were only put on treatment diets for 4 weeks before being transferred to the finisher accommodation. The relatively shorter period of dietary treatment in the weaner stage and the possible influence from the exposure to the novel diet could explain why no clear effect on growth was found.

In terms of enrichment provision, weaners receiving wood tended to have higher tail lesion scores, and more weaners were removed in the wood pens. This was also shown in the total number of pigs affected during the finisher stage (removed for treatment, removed as biters or injected with antibiotics), where pigs which had wood as finishers fed with the standard diet had lower number of pigs affected per pen. Finishers which had the floor toy also had higher ear lesion scores. These results suggested that when only a single enrichment device is available, the rubber floor toy for weaners and the spruce post for finishers were more effective in reducing lesion scores. Docking et al. (2008) showed that pigs at different ages used enrichment items differently. Van de Weerd and Day (2009) carried out an extensive review of enrichment for pigs and reported that pigs' interest in specific objects could change overtime based on their own behavioural development. The rubber floor toy has soft, chewable arms, and as it is located on central floor area, it might be more readily accessible for weaners to suckle and manipulate than the spruce wooden post, which is harder and might require more skill to chew and use. Enrichment provision should be based on the properties suitable for different ages of the pigs, and appropriate enrichment provision would have a positive effect to improve physical scores.

Nevertheless, the overall impact of tail biting in this study was severe, and the effectiveness between either of the two enrichment items was marginal. Based on the authors' knowledge, no study to date has yet demonstrated the possibility of managing tail biting in undocked pigs without loose rooting materials provided on the floor or via dispensers. It is accepted that the natural motivation to explore and forage is a major cause for pigs to tail bite (Brunberg et al., 2016; Valros, 2018). Bracke (2018) proposed the concept that for an environmental enrichment to be considered "proper," it should provide occupation and also be able to prevent abnormal behaviours. The basic enrichment provision used in this study, however, is still fairly common on many commercial farms, which was the reason why this level of provision was used in order to reflect commercial practice. Indeed, in Irish commercial units where point source enrichment items are the most commonly used (Haigh and O'Driscoll, 2019), there is normally a much higher pigs to enrichment ratio, than in this study (van Staaveren et al., 2019), and thus the strategy employed represents an improvement over the typical situation. The current study found that pigs interacted with the enrichment items, and that this interaction did not decrease overtime, suggesting they have some occupation value beyond novelty to the pigs. Nevertheless, the enrichment items were still insufficient to stop intact-tailed pigs from tail biting. This might also explain why although in the finisher stage a higher interaction with the floor toy was recorded, the tail lesions were not improved, and the increased use of the enrichment did not contribute to less frequent tail biting either.

Despite the numerous tail biting outbreaks recorded, overall tail lesion scores in the current experiment were lower than expected. In fact they were lower than those recorded in another study with undocked pigs, which recorded no tail biting outbreak (Chou et al., 2019b). The low tail lesion scores are likely due to the timing of the scoring: pigs were scored every 2 weeks, and based on the experimenter's experience, tail lesions tend to heal quickly. Based on a previous study on the histopathology of tail docking, superficial healing of the tail injury could take 3-7 days depending on the severity (Sandercock et al., 2016). Therefore, the scorings might not reflect lesions at their worst state immediately post-biting and might underestimate the severity of tail biting. Moreover, the tail scoring system used in the current experiment is likely more sensitive at distinguishing the severity of fresh lesions, rather than older lesions. This could also explain why all differences in tail lesions between treatments were only picked up in the finisher stage, due to the accumulative consequence of prolonged tail biting. Furthermore, tail biting events peaked between 3-7 weeks post-weaning in the current study, hence the mean tail score overtime could also result in a lower score and was less indicative of the level of tail biting, compared to tail amputation score or the number of pigs removed and treated.

In conclusion, this study showed that simply increasing dietary fibre level and a single point-source enrichment at a 14:1 pig to enrichment ratio in this study was not enough to control tail biting in pigs with intact tails, even if the enrichment item is relatively favourable to pigs. Severe tail biting was prevalent across all treatments and proved difficult to control. Pigs provided with a higher fibre diet had higher tail lesion scores and performed more tail biting behaviours. The enrichment item which we considered suitable for use in the different stages (floor toy for weaners and spruce post for finishers) was slightly more effective than its counterpart in alleviating the severity of tail lesions, however, neither of them succeeded in reducing the risk of tail biting. More advanced strategies taking into consideration the complex factors behind tail biting are needed to manage tail biting in undocked pigs on fully-slatted systems.

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Declaration of interest

The authors declare no conflict of interest.

Ethics committee

All procedures in the experiment were approved by the Teagasc Animal Ethics Committee (TAEC124/2016).

Software and data repository resources

Data could be made available on request.

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Tables

Table 1 *Formulation and chemical analysis of treatment diets in different stages*

	Weaner		Finisher	
	Standard	High	Standard	High
Ingredients (%)				
Wheat feed flour	38.00	37.00	45.37	47.56
Soybean meal (48% protein)	25.00	25.00	13.50	13.50
Maize	15.36	10.01	5.89	5.80
Barley	18.00	9.70	24.00	-
Soybean hulls	-	10.45	8.50	26.30
Wheat bran	-	1.00	-	-
Vegetable oil	1.00	4.20	0.10	4.20
Calcium carbonate	1.25	1.25	1.25	1.25
DL-Methionine	0.08	0.08	0.08	0.08
L-Lysine HCl	0.44	0.44	0.44	0.44
L-Threonine	0.11	0.11	0.11	0.11
Monocalcium phosphate	0.37	0.37	0.37	0.37
Sodium chloride	0.30	0.30	0.30	0.30
Vitamin and trace mineral mixture	0.10	0.10	0.10	0.10
Chemical analysis (g/kg feedstuff)				
Dry matter	885	888	883	888
Crude ash	45	47	40	45
Crude protein	196	193	142	154
Crude fibre	37	53	59	116
Neutral detergent fibre	106	142	146	240
Acid detergent fibre	45	74	78	155
Acid detergent lignin	8	9	10	14
Metabolisable energy (MJ/kg)	13.7	13.5	12.5	10.8
Digestible energy (kcal/kg dry matter)[†]	3883.7	3796.8	3570.7	3275.8

[†] The digestible energy was calculated by the formula with the highest regression coefficient and lowest residual standard deviation of the prediction values described in Noblet and Perez (1993).

Table 2 Total number of pigs removed as tail bitten victims or biters, and injected in the home pens for tail biting interventions, and the number of tail biting outbreaks recorded in different treatment groups. Numbers in brackets are pigs removed as victims as part of the tail biting outbreak protocol.

	Removed as victims[†]	Removed as biters	Injected in home pens	Number of outbreaks
Diet[*]				
High	89 (75)	17	29	14
Low	60 (46)	19	20	12
Subtotal	149 (121)	36	49	16
Weaner enrichment				
Toy	60 (41)	15	27	8
Wood	86 (69)	28	22	12
Finisher enrichment				
Toy	26 (16)	10	1	4
Wood	22 (12)	5	2	2
Overall enrichment				
Toy - Toy	32 (18)	9	14	4
Toy - Wood	45 (29)	11	15	6
Wood - Toy	65 (50)	25	14	11
Wood - Wood	52 (36)	13	9	5
Subtotal	194 (133)	58	52	26

[†] As described in the tail biting management procedures, pigs were also removed for tail treatments whenever necessary for ethical reasons, in pens without reaching the tail biting outbreak criteria.

[*] The dietary treatment began in week 4 post-weaning and therefore the numbers prior to this time were excluded.

Table 3 *Ethogram for direct behaviour observation*

Behaviours	Description of behaviour
Tail manipulation	Tail-in-mouth behaviour on another pig
Tail manipulation at the feeder	Tail-in-mouth behaviour on another pig which is feeding
Ear manipulation	Ear-in-mouth behaviour on another pig
Manipulation in other regions	Manipulation with mouth open of another pig in a body part other than tail and ear, e.g. face, snout, hock, or genital
Belly-nosing	Rubbing/manipulating a pen mate's belly/flank region with a rhythmic up-and-down movement
Mounting	Having 2 front legs on the back of a pen mate
Engaging in aggression behaviour	Pushing, aggressive biting, headknocking, fighting with pen mates, excluding play-fighting
Aggression behaviour at the feeder	Performing the above aggression behaviour during feeding or towards a pig that is feeding
Individual play	Scampering, pivoting, head tossing, flopping, and pawing (Newberry et al., 1988; Donaldson et al., 2002), excluding social play
Interactions with enrichment[1]	
Biting device	Oral manipulation of the device with the mouth open
Rooting device	Nasal manipulation of the device by manoeuvring the device with the snout
Aggressive encounter	Biting, headknocking or pushing other pigs over access to the device
Other	Physical contact with the device other than mouth or snout (limbs, body, etc.)

[1] If ropes were present in the pen due to outbreak control, they were recorded separately.

Table 4 *Selected behaviour outcomes and the treatment effects in different production stages. Behaviours were analysed as frequency/pig/min (mean ± s.e.). Different superscripts between two columns of the treatment within the same stage denote significant difference. No difference was found in interactions between treatments. (Small letters denotes differences at P < 0.05 and capital letters at P < 0.001)*

	Enrichment						Fibre level			
	Weaner		Finisher		Overall[1]					
Behaviour	Toy	Wood	Toy	Wood	Toy	Wood	Standard	High	S.E.	*P*-value
Tail biting										
Overall	0.011	0.014	-	-	0.011	0.014	0.010^{a}	0.015^{b}	0.001	< 0.05
Weaner stage	0.019	0.024	-	-	-	-	0.018^{a}	0.025^{b}	0.002	< 0.05
Finisher stage	0.006	0.008	0.006	0.008	-	-	0.006	0.008	0.002	> 0.05
All harmful[2]										
Overall	0.031	0.034	-	-	0.030	0.035	0.030	0.035	0.010	> 0.05
Weaner stage	0.042^{a}	0.051^{b}	-	-	-	-	0.042^{a}	0.051^{b}	0.013	< 0.05
Finisher stage	0.029	0.026	0.027	0.028	-	-	0.027	0.028	0.003	> 0.05
Enrichment[3]										
Overall	0.099^{A}	0.075^{B}	-	-	0.109^{A}	0.067^{B}	0.091	0.085	0.004	< 0.001
Weaner stage	0.118^{A}	0.067^{B}	-	-	-	-	0.093	0.092	0.006	< 0.001
Finisher stage	0.083	0.082	0.098^{A}	0.067^{B}	-	-	0.088	0.077	0.006	< 0.001

1 When analysing the overall effect of the enrichment, only the enrichment at the time of recording was used as the fixed effect.
2 All harmful = tail biting + ear biting + biting other parts of the body + belly-nosing
3 Enrichment = bite + root + other contact with the device

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Figure 1 Spruce (*Picea sitchensis*) post provided in the Funbar® dispenser.

Figure 2 The percentage of pigs in the finisher stage within each tail score category A) tail damage score when provided with a rubber floor toy or wood in the weaner stage, B) tail blood score when provided with a rubber floor toy or wood in the weaner stage (pigs received wood tended to have higher overall tail lesion score than toy; P =0.08), and C) tail damage score when provided with a standard (5.9%) or high (11.6%) dietary fibre level (pigs with high fibre diet had higher tail damage score than standard; P = 0.04). Tail 'damage' was scored from 0-3 (0: intact, 1: bite marks, 2 open wound, 3: swollen bite wound), and 'blood' was also scored from 0-3 (0-3 scale; 0: no blood, 1: dry blood/black scar, 2: older red blood, 3: fresh blood).

Figure 3 The percentage of pigs within each category of the ear lesion score in the finisher stage, when given toy or wood in the finisher stage (pigs with wood had higher ear lesion scores than toy, P < 0.01). Ear lesions were scored from 0-4 (0: undamaged, 1: superficial scratches, 2: evidence of recent bleeding, 3: bloody and red, 4: part of ear missing).

Figure 4 The level of performance of selected behaviours across time (frequency/pig/min (mean ± s.e.)). A) All recorded behaviours combined (Table 3, P < 0.001), B) tail biting (P < 0.001) and C) all interactions with the enrichment (bite + root + other contact with the device, P > 0.05).

Figure 1 Spruce (*Picea sitchensis*) post provided in the Funbar® dispenser.

Figure2

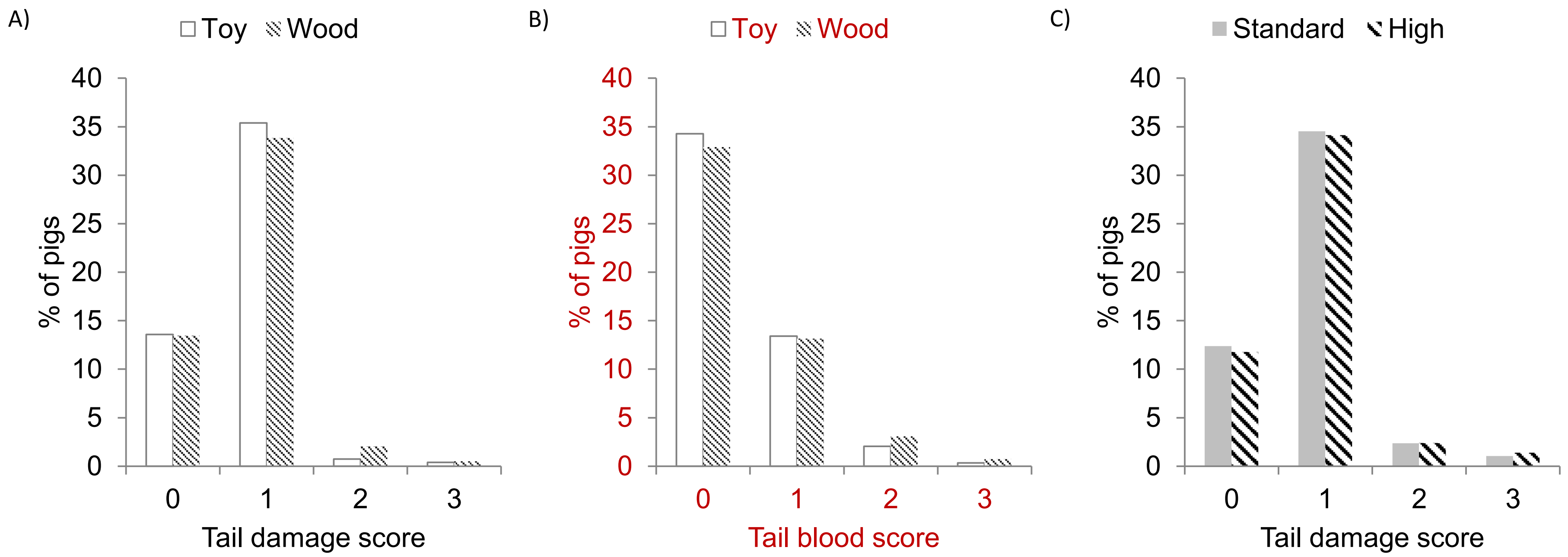

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Figure3

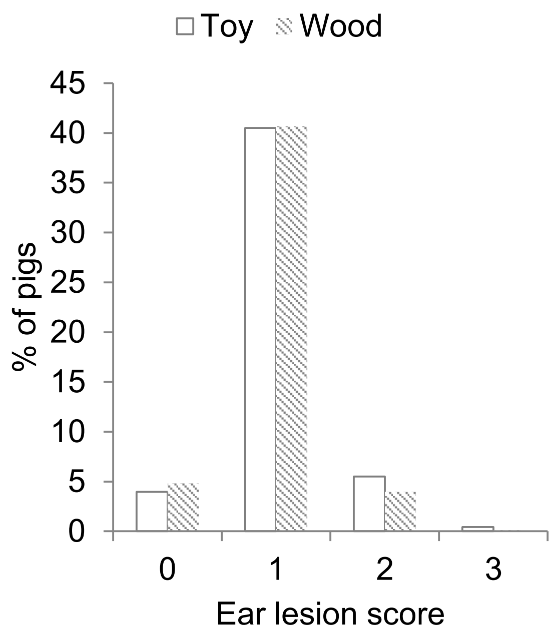

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Figure4

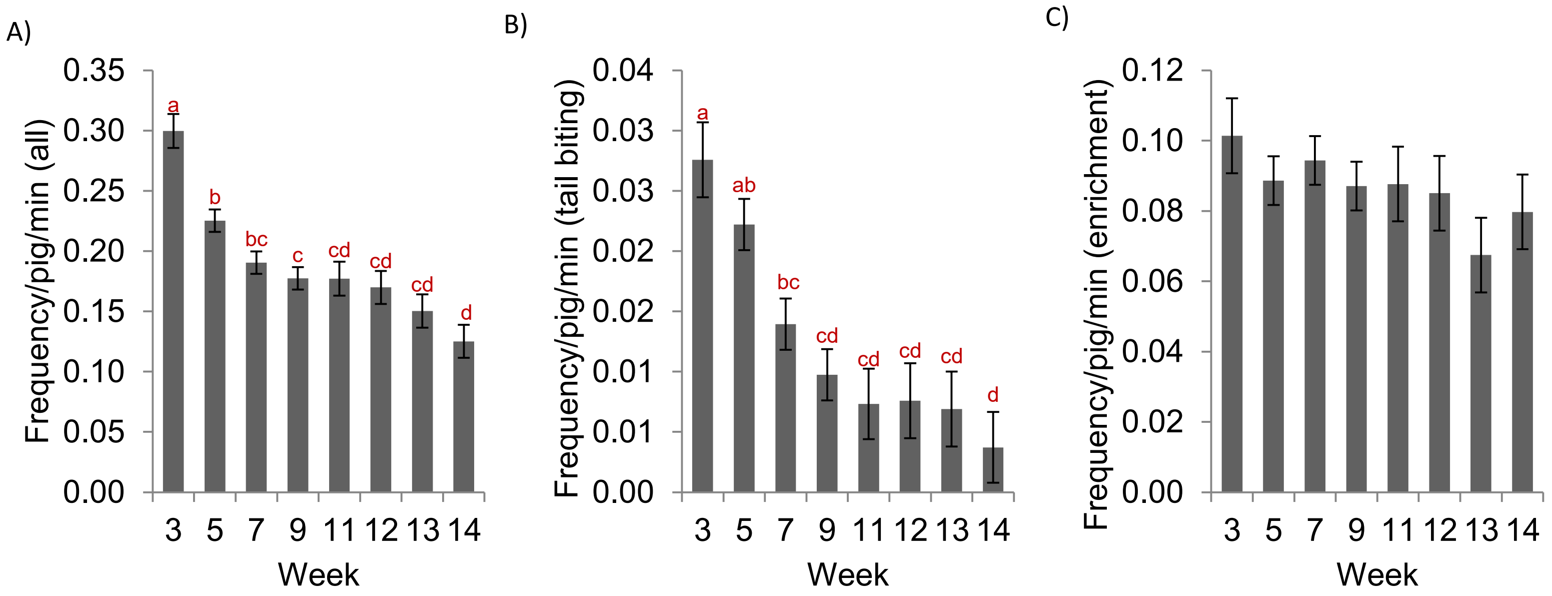

Figure 4 The level of performance of selected behaviours across time (frequency/pig/min (mean ± s.e.)). A) All recorded behaviours combined (Table 3, $P < 0.001$), B) tail biting ($P < 0.001$) and C) all interactions with the enrichment (bite + root + other contact with the device, $P > 0.1$).

Discussion of Chapter 5

This chapter addressed the main objective of the thesis, which was to find economically feasible strategies to manage tail biting in undocked pigs on fully-slatted floors. The strategy that is the easiest to apply in commercial practice is to change the composition of the diet. Fibrous diets have been shown to reduce feather pecking in laying hens (van Krimpen et al., 2005; Brunberg et al., 2016), but no published study has looked at its effect on tail biting in pigs. In terms of enrichment, minimal provision was used, so as to be similar to current practices on Irish commercial farms (Boyle et al., 2019). The enrichment items compared were a spruce post and a rubber floor toy, as these were shown to be preferred by pigs in Chapter 4. In Chapter 4, pigs (finishers) provided with either the spruce or the floor toy did not differ in tail lesion score; however, in the current study, pigs provided with the rubber floor toy during the finisher stage had higher tail lesion scores than those with the spruce post. In the weaner stage, on the contrary, pigs with the floor toy had lower tail lesion scores than those with spruce. Thus, in terms of tail lesions, this study demonstrated that between the two items trialled, spruce was a better enrichment for finisher pigs, and this type of rubber floor toy was better for weaner pigs. This adds to the findings in Chapters 3 and 4, where only finishers were used. Both in this chapter and in Chapter 3, the overall interaction with the wood post did not differ between weeks, although a slight declining trend was found. It should be noted that in Chapter 3 and the current chapter, similar sampling was used (3 or 5-min direct observation) whilst in Chapter 4, a 1-hour continuous video sampling was used. This might cause a difference in the behaviours recorded between studies.

However, the overall high level of tail biting across treatments in the current study overshadowed any effect of the treatments, and suggests that simply using a high fibre diet with this minimal level of enrichment provision is not effective in reducing tail biting in undocked pigs. From this point, the direction of the thesis moved towards using a more complex type of enrichment provision, which will be discussed in detail in the next chapter.

Chapter 6 A high enrichment replenishment rate reduces damaging behaviours and increases growth rate in undocked pigs kept in fully-slatted pens

This chapter had been previously presented as an oral presentation in: **Chou, J.-Y.**, Sandercock, D. A., D'Eath, R. B. and O'Driscoll, K. 2019. Managing tail biting in undocked pigs on fully-slatted floors with different enrichment strategies. Proceedings of the 70th Annual Meeting of the European Federation of Animal Science (EAAP), 26-30 Aug, Ghent, Belgium.

Introduction to Chapter 6

Following the failure of the attempt to control tail biting in undocked pigs in Chapter 5, by using a high fibre diet combined with provision of one preferred enrichment item per 14 pigs, the pressing question at hand was whether it is even possible to rear undocked pigs in the current fully-slatted system without structural changes. Therefore, a pilot study (Chou et al., 2019, not included in the thesis) was conducted prior to the next stage of the thesis, using undocked pigs. In this study, 8 litters of all piglets were provided with a variety of forms of enrichment pre-weaning (a piece of hessian cloth, a small paper cup, a chewable plastic toy and a piece of chopped bamboo). Post-weaning, pigs were reared in groups of 12, and eight enrichment items that are compatible with fully-slatted floors, and which between them fulfilled the criteria identified by van de Weerd et al. (2003; i.e. rootable, destructible, edible) were provided in each pen. This was to understand the extent to which post-weaning enrichment and management under the constraints of current housing systems can help alleviate tail biting in undocked pigs. This pilot study also investigated whether varying the multiple enrichment items with an interval of two weeks further reduced the amount of tail biting compared to having the same multiple items over time. In this study, the overall level of tail biting was low; only one out of 96 pigs used in the study had tail loss. Varying the enrichment did not bring further advantages in terms of tail biting outcomes. Based on these results, one optimal combination of eight enrichment items, which were more interacted by the pigs, relatively durable, requiring less frequent replacement, easily and cheaply available and locally sourced, was selected for the current study, and different replenishment frequencies of these eight items were compared in order to understand the economic outcome and consequently the feasibility of this type of enrichment strategy on commercial farms. Furthermore, whether or not piglets were given enrichment pre-weaning was also included in the investigation. For the pilot study, I contributed to the experimental design, partial data collection, statistical analysis, data presentation, original draft editing and review and editing of the final publication. The main data collection and the original draft of the study was carried out by the intern student Constance Drique, and therefore it is not included in the thesis.

6.1 Abstract

EU Council Directive (2008/120/EC) prohibits the routine practice of tail docking to control tail biting in pigs, yet most pigs in Europe are still tail-docked. One of the difficulties in complying with the prohibition of docking is a lack of effective alternative solutions, especially in fully-slatted systems. This study compared three enrichment strategies for pigs which are compatible with fully-slatted floors. Forty-eight pens (12 pigs/pen, n=576) of undocked pigs were followed from birth to slaughter in a 2x3 factorial design. Half the pigs (24 pens) were exposed to an enriched environment pre-weaning (coconut, rubber toy, hessian and bamboo). All pens received the same enrichment (8 items/pen, including an elevated rack supplied with fresh-cut grass, and objects of wooden, bamboo, rubber and fabric materials presented in various ways) post weaning. However, three replenishment frequencies were applied; "Low" (replenished Monday/Wednesday/Friday), "Medium" (replenished once daily), and "High" (replenished as soon as a material was depleted (i.e. *ad libitum*)). Individual pig weights were obtained at D0, D49, D91 and D113 post-weaning. Direct behaviour observations were conducted twice weekly. Tail and ear lesion scores of individual pigs were recorded every other week. The average performance data of pigs in the current study ("undocked enriched") were compared to a parallel study using docked pigs with minimal enrichment ("docked barren") during the same time period, on the same research farm. The average daily gain in the finishing stage was higher in "High" than "Low" enrichment replenishment rate pigs (1.10±0.01 vs. 1.07±0.01 kg, $p<0.05$). "Low" pigs also performed more damaging behaviours (tail/ear biting, belly-nosing, mounting, other biting and aggressive behaviours combined) than "High" and "Medium" pigs ($p<0.01$). Frequency of overall interaction with the enrichment did not differ between post-weaning treatments. Pre-weaning exposure to enrichment only contributed to a lower ear lesion score post-weaning ($p=0.04$). No difference in lesion scores was found between post-weaning treatments. Although sporadic tail biting outbreaks occurred (n=14), they usually resolved within 2 weeks (13.3±4.5 days), and all but one tail-injured pig were successfully reintroduced back to their

home pens after removals. The “undocked enriched” scenario generated a higher net margin per pig over “docked barren.” Overall, the level of tail biting was greatly reduced compared to the previous chapter (**Chapter 5**), and pigs in the current study generated more profit than minimally enriched, docked pigs, despite the higher cost of enrichment. Furthermore, *ad libitum* access to enrichment had a positive effect on pigs’ growth, and reduced injurious behaviours.

6.2 Introduction

Although it has been more than a decade since the ban on routine tail docking to control tail biting was codified into Council Directive 2008/120/EC, the search for solutions to manage tail biting and to implement the non-docking policy is still on-going. The reason why this policy was not readily implemented is due to a multitude of factors, including the unpredictability of tail biting, its multifactorial nature, difficulty in its management, reluctance to change current rearing practices, and higher production costs associated with rearing undocked pigs (Nalon and De Briyne, 2019). Tail docking is also still commonly practised because it does reduce the risk of tail biting. Lahrmann et al. (2017) found more frequent tail biting behaviours and worse tail lesions when pigs were not docked, compared to their docked counterparts, in the same herd with identical management practices. However, even among docked pigs, tail lesions can still be observed in slaughterhouse inspections (Harley et al., 2012), which suggests that docking only reduces the severity of tail biting rather than preventing it entirely.

Other than docking status, another important risk factor for tail biting is the availability of manipulative materials as environmental enrichment. Effective enrichment should be able to stimulate species-specific behaviours and prevent damaging behaviours. Thus, enrichment should allow pigs to investigate, manipulate, chew and ingest (van de Weerd and Ison, 2019), and sustain their interest. Provision of loose bedding materials such as straw satisfies these criteria and is considered one of the most effective ways to reduce tail biting (Scollo et al., 2013; Studnitz et al., 2007; van de Weerd et al., 2006), but on fully-slatted floors straw can block the slurry system (D'Eath et al., 2014). Many studies have investigated alternative ways of supplying loose materials that are compatible with slatted floors: in elevated fittings (Bulens et al., 2015; Chou et al., 2019; Holling et al., 2017; Zonderland et al., 2008; Zwicker et al., 2013, 2012), as a compressed form in solid blocks (Zwicker et al., 2013, Haigh et al., 2019), or in floor feeders (Veit et al., 2016). However, simply providing loose materials in a fixed location is not as effective in reducing tail biting in undocked pigs as provision of material on the floor (Veit et al. 2016, Zonderland et al. 2008). In contrast, combining the provision of loose materials in a smaller quantity with other point-source enrichment items has been more effective in managing tail biting in undocked pigs (Telkänranta et al., 2014a, Chou et al. 2019, not included in the thesis).

Although the benefit of enrichment on reducing the risk of tail biting has been widely acknowledged among stakeholders (De Briyne et al., 2018), the awareness of its importance and the uptake of suitable enrichment materials in commercial practices in the EU has still been low (De Briyne et al., 2018, Van de Weerd & Ison, 2019). A significant obstacle is the perceived negative economic impact on production costs, in terms of the supply of the actual materials, and the extra labour required for maintenance (D'Eath et al., 2016). In order to reduce these costs, some producers use objects that are either of inappropriate materials or presentation, which could even lead to negative effects on pig welfare (Van de Weerd & Ison, 2019). On the other hand, the benefit of appropriate enrichment provision on pigs' performance is well documented (Averós et al., 2010; van de Weerd and Day, 2009). An optimal enrichment solution needs to strike a balance between allowing pigs to thrive in their environment without the need for tail docking, and minimising labour and cost. Research is needed to identify this balancing point, and determine whether the costs associated with rearing undocked pigs with appropriate enrichment provision will be offset by benefits to the pigs' health, performance and carcass traits.

Beside the rearing environment during the growing and finishing stages, there is some evidence that the pre-weaning environment has an impact on the risk of tail biting. Weaned pigs, which were housed on partly-slatted floors with a single rubber hanging 'toy', performed fewer pig-directed manipulative behaviours if they had been provided with an enriched environment pre-weaning, than if it was barren (van de Weerd et al., 2005). However, if pigs were housed in straw-bedded pens post-weaning, there was no effect of pre-weaning environment on the frequency of damaging behaviours. Likewise, Telkänranta et al. (2014b) found pigs performed fewer manipulative behaviours directed towards other pigs with the snout or mouth, and had a lower percentage of severe or mild tail lesions 5 weeks post-weaning, when they had been housed in a more enriched environment (rope, newspaper, ball and wood shavings compared with only ball and wood shavings) pre-weaning. On the other hand, some studies reported no difference in terms of post-weaning tail biting behaviours or tail lesions between early-enriched (with substrates such as straw, peat and wood shavings) and barren pigs (Oostindjer et al., 2011; Statham et al., 2011). Thus, further investigation is needed to understand how pigs' early life experience with enrichment can affect their performance of damaging behaviours later in life, especially in the context of fully-slatted systems.

Besides common methods used to assess the amount of damaging behaviours being performed (e.g. behaviour observations, tail and ear lesion scoring, and tail posture), other novel measures, such as tear staining and tail lateralisation can provide insight into the welfare state of the animals. Tear staining is a relatively new tool in pigs which can be used to assess welfare, having previously been validated in laboratory rodents (Mason et al., 2004). Greater coverage of tear stains is associated with chronic stress in socially-isolated pigs (DeBoer et al., 2015), but the relationship with other stressors such as tail and ear lesions, or access to enrichment, has been less pronounced (Telkänranta et al., 2016). In one of our previous studies (**Chapter 3**), tear stain scores were found to be weakly correlated with ear lesion scores at pen level, although no such relationship was found in the following study (**Chapter 4**). In Chapter 5, pigs fed a high fibre diet had lower tear staining scores than a standard fibre diet. Similar to what Larsen et al. (2019) found, this could be related to pigs' growth rate, as they found higher growth associated with higher tear staining scores. Thus, although tear staining has potential to be an easy-to-use on-farm welfare assessment tool for pigs (**Chapter 3**, Telkänranta et al., 2016), more evidence is needed to establish a relationship with damaging behaviours or enrichment provision.

Cerebral lateralisation in vertebrates (i.e. different functions are linked to the right or left hemisphere) is linked with emotional processing in the brain (Leliveld et al., 2013), the complexity of the activity performed (Goursot et al., 2018), and the response to pain and stress (Rogers, 2010). The majority of research on lateral bias in pigs has focused on side preference during sows' nursing behaviour (Goursot et al., 2018), and these authors were the first to report lateralisation in growing pigs in terms of various motor functions and behaviours, including tail lateralisation. Therefore, very little is yet known about pigs' lateralisation, and whether tail lateralisation is associated with tail biting behaviour. In the current study, tear staining and tail lateralisation were recorded in addition to lesion scoring to explore possible links with tail biting or different enrichment treatments.

The previous chapter (**Chapter 5**) showed that one enrichment item per 14 pigs combined with a high dietary fibre level was not sufficient in reducing the risk of tail biting in undocked pigs. Hence, this study employed a more complex enrichment strategy with a slightly reduced stocking density as a result of the pilot study (Chou et al., 2019, not included in the thesis). The effect of early exposure to environmental enrichment pre-weaning, combined with three different enrichment management strategies post-weaning, was assessed. All enrichment materials used from farrow to finish were compatible with fully-slatted systems and, based on the pilot study, were shown to be biologically relevant to satisfy pigs' explorative behaviours (Chou et al., 2019, not included in the thesis). The three different management strategies have different associated amounts of labour and cost. Here it is hypothesised that early exposure to an enriched environment, and a high enrichment replenishment rate, will reduce tail biting behaviour and tail lesions. An additional aim was to calculate the economic costs and benefits of this complex enrichment strategy in comparison to a standard production situation (low enrichment with docked pigs).

6.3 Materials and methods

6.3.1 Animals and housing

A total of 576 pigs, born over 5 batches in the Teagasc Moorepark Research unit (Ireland), were used in the study. Another unrelated study was conducted concurrently in the same research unit, and thus at farrowing, half of the sows in each batch (6-15 sows) were assigned to each study. A 3-week batch farrowing system was practiced, and therefore piglets in batches one to four were born 3 weeks apart. The fifth batch farrowed 15 weeks after the fourth batch, and was used to compensate for a lower than expected number of animals available in batch 2, to reach the targeted sample size. After farrowing, piglets were teeth-clipped to prevent excessive damage to their faces and the sows' udder. The pigs' tails were left undocked, and male pigs were not castrated. All piglets were individually tagged on the left ear with a tag of a predetermined colour for identification. In each farrowing crate, one 1.2 m synthetic hemp rope was hung near the feeding trough as enrichment for the sows (Figure 6.1). The temperature was kept at 24 degrees after farrowing with a heat pad to maintain piglets' thermal comfort. The farrowing pens had fully-slatted floors except the heat pad area. One nipple drinker was provided in each farrowing pen. Creep feed was provided daily, starting from one week before weaning.

Pigs were weaned at 4 weeks of age. Two days before weaning all pigs were individually weighed and randomly allocated to their post-weaning treatment (12 pigs/pen). Allocation was balanced for pre-weaning treatment, weight, sex (six male and six female) and litter mates (with 2-4 litter mates together in each pen). Piglets with open wounds on the tail and lower than 4 kg body weight were not selected. Once pigs were allocated to a pen, another coloured tag was applied to the right ear

1 day before weaning, so that each pig in the same pen had a different coloured ear tag combination. This was for individual id during behaviour observations.

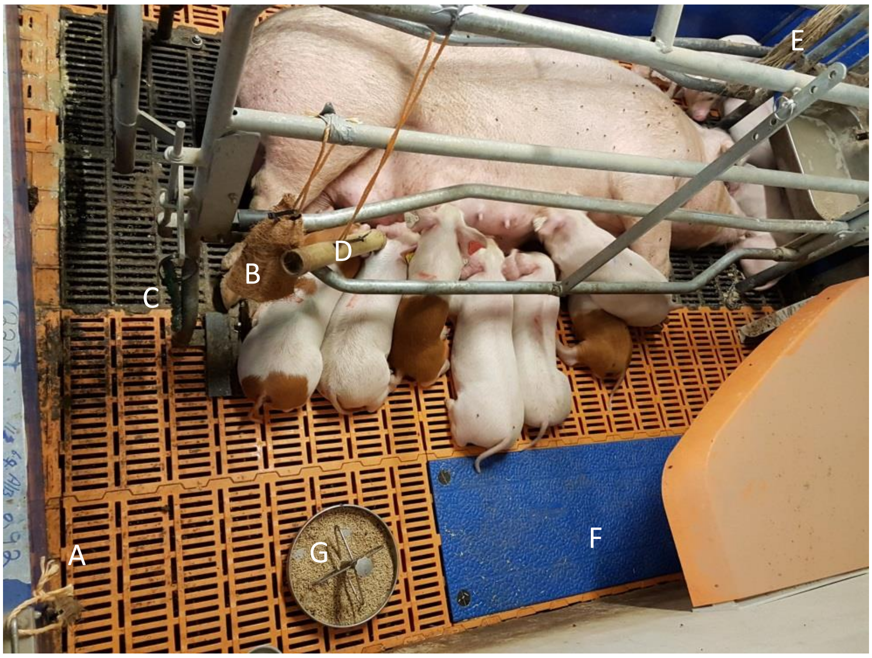

Figure 6.1. The enriched farrowing pen as shown in photograph. A) Hessian sack B) Coconut basket C) Chewable toy D) Bamboo piece E) Rope for sow F) Heat pad G) Creep feed

At weaning, all piglets were transported by a wheelbarrow to the weaner accommodation and mixed into their treatment groups. A standard pelleted diet was provided *ad libitum* by a wet-dry feeding system consisting of single space feeders. Water was also provided *ad libitum* in a separate nipple drinker. During the first week post-weaning, a starter diet was provided (Startrite 88, Provimi, Ireland), then a standard home-milled link diet for 2 weeks, before a standard commercial diet was provided (net energy 10.99/9.67 MJ/kg, protein 17.9%/16.18%, crude fibre 3.3%/5.06% for weaners and finishers respectively).

Weaner pens were 2.4 m x 2.6 m in dimension with fully-slatted plastic floors. Pigs were transferred to the finisher facilities 7 weeks post-weaning (i.e. 11 weeks of age), and the finishing pens were dimensioned 4 m x 2.4 m with fully-slatted concrete floors. The group composition was maintained from weaning without mixing until slaughter. The temperature was maintained at 27-28°C immediately post-weaning by a computer-controlled heating and mechanical ventilation and reduced 2 degrees every 2 weeks thereafter in the weaner house. In the finisher house the temperature was kept at 20°C with the same computerised system, but without heating. Artificial lighting (around 150 lux and 130 lux in the weaner and finisher house respectively) was provided between 0700h and 1700h to supplement natural light from windows, and promote a normal circadian rhythm.

6.3.2 Experimental design

The study used a 2 × 3 design: enriched or barren environment pre-weaning and three different enrichment management strategies post-weaning (Table 6.1).

Table 6.1. Treatment blocking plan

Treatment	1	2	3	4	5	6
Pre-weaning	Enriched	Enriched	Enriched	Barren	Barren	Barren
Post-weaning	High	Medium	Low	High	Medium	Low

One week after birth, litters included in the study were allocated to two pre-weaning treatments, balanced as much as possible for litter size, location in the farrowing house and the ratio of male/female offspring. Half of the pens were enriched ("Enriched") with a hessian sack (0.2 × 0.2 m), a coconut basket (around 0.25 × 0.2 m), a chewable toy (0.25 m), and a bamboo piece (0.3 m, Figure 6.1 and 6.2), and the other half were kept barren ("Barren", other than the rope for the sow). The hessian sack and the coconut basket were provided one week after birth, the chewable toy in the following week, and the bamboo piece a week thereafter. All enrichment was suspended and was replenished if depleted.

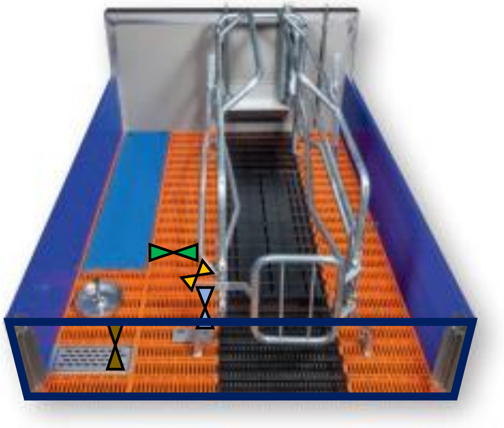

Figure 6.2. The empty enriched farrowing pen with the locations of the enrichment shown in schematic drawing (Brown: hessian sack, Yellow: coconut basket, Blue: chewable toy and Green: bamboo piece) (Photo source: Big Dutchman)

All pigs were provided with the same eight enrichment items throughout their lives post-weaning (Table 6.2). These were selected so that they were appropriate to the pigs' age in the weaner and finisher stages. In the pilot study (Chou et al., 2019, not included in the thesis), a large range of enrichment materials was used, without major tail biting outbreaks, so the most interacted with and sustainable materials were chosen for this study. The materials were categorised based on different properties identified in van de Weerd et al. (2003). The full list of enrichment used during the weaner and finisher stage in the study is shown in Table 6.2. Most items which could be used up or worn out were made of organic and biodegradable materials for the health and safety of the pigs.

Three different post-weaning enrichment replenishment strategies were as follows:

"High" (*ad libitum*): A rack of loose material was checked twice to three times daily (around 0900-1000h, 1400-1500 and 1800-1900h) and immediately replenished if depleted, so that it was effectively provided *ad libitum*. All other destructible items were replaced immediately once it was noticed they were depleted.

"Medium": The loose material was replenished with a reduced quantity (Table 6.2) once daily if depleted and other destructible items were replenished 48 hours after depletion.

“Low”: The loose material was replenished only on Monday/Wednesday/Friday if depleted with the same reduced quantity as “Medium,” and other destructible items were replenished one week after depletion.

The quantity of the loose material (fresh cut grass) which was provided during replenishment was determined using data gathered during a pilot study (Chou et al., 2019, not included in the thesis), and varied with the pigs’ age (Table 6.3). Before the start of the study, the experimenter calculated the approximate weight

Table 6.2. Enrichment combination list with properties of categorisation

Stage	Properties of enrichment						Item	Method of provision
	Rootability	Durability	Edibility	Texture	Presentation	Location		
Weaner	Rootable	Deformable	Chewable	soft	Moveable	Floor level	Easyfix® Luna 117	Loose on floor
Weaner	Rootable	Deformable	Chewable	soft	Moveable	Floor level	Easyfix® Luna 117	Loose on floor
Weaner	Rootable	Destructible	Ingestible	hard	Attached	Floor level	Spruce (*Picea sitchensis*) post (1.2 × 0.05 × 0.04m)	Placed in dispenser
Weaner	non-rootable	Destructible	Ingestible	hard	suspended	Eye level	Pine (*Pinus sylvestris L.*) block (0.2 × 0.05 × 0.05m)	Attached on chain
Weaner	non-rootable	Renewed	Ingestible	loose	Attached	Eye level	Fresh-cut grass	In an elevated rack
Weaner	non-rootable	Destructible	Chewable	soft	suspended	Eye level	Cardboard tube (0.33m)	Tied on pen
Weaner	non-rootable	Deformable	Chewable	soft	suspended	Eye level	Rubber pipe	Attached on chain
Weaner	non-rootable	Destructible	Chewable	hard	suspended	Eye level	2 Ayous *(Triplochiton scleroxylon)* sticks (0.15 × 0.03m)	Attached on chain
Finisher	Rootable	Destructible	Chewable	hard	Moveable	Floor level	Larch (*Larix decidua*) floor toy	Loose on floor
Finisher	Rootable	Destructible	Chewable	hard	Moveable	Floor level	Spruce floor toy	Loose on floor
Finisher	Rootable	Destructible	Ingestible	hard	Attached	Floor level	Larch post (1.2 × 0.08 × 0.04m)	Placed in dispenser
Finisher	non-rootable	Destructible	Ingestible	hard	suspended	Eye level	Spruce piece (0.33 × 0.05 × 0.04m)	Attached on chain
Finisher	non-rootable	Renewed	Ingestible	loose	Attached	Eye level	Fresh-cut grass	In an elevated rack
Finisher	non-rootable	Destructible	Chewable	soft	suspended	Eye level	Potato hessian bag (0.5 × 0.76m)	Tied on pen
Finisher	non-rootable	Deformable	Chewable	soft	suspended	Eye level	Easyfix® Astro 200	Attached on chain
Finisher	non-rootable	Destructible	Chewable	hard	suspended	Eye level	Bamboo (0.3 cm)	Attached on chain

of a handful of grass (a small handful was around 0.3 kg and a big handful around 0.5 kg). The number of handfuls which were used to replenish the material was then recorded to provide an estimation of the weight of the grass provided (Figure 6.3). This method was used to facilitate efficient replenishment of grass during the trial work.

Table 6.3. Quantity of supply of the loose material (fresh-cut grass)

Quantity	Weaner wk 1-3	Weaner wk 4-7	Finisher wk 1-7	Finisher wk 8-9
High	0.5 kg	1 kg	1.5 kg	1 kg
Medium / Low	0.3 kg	0.5 kg	1 kg	0.5 kg

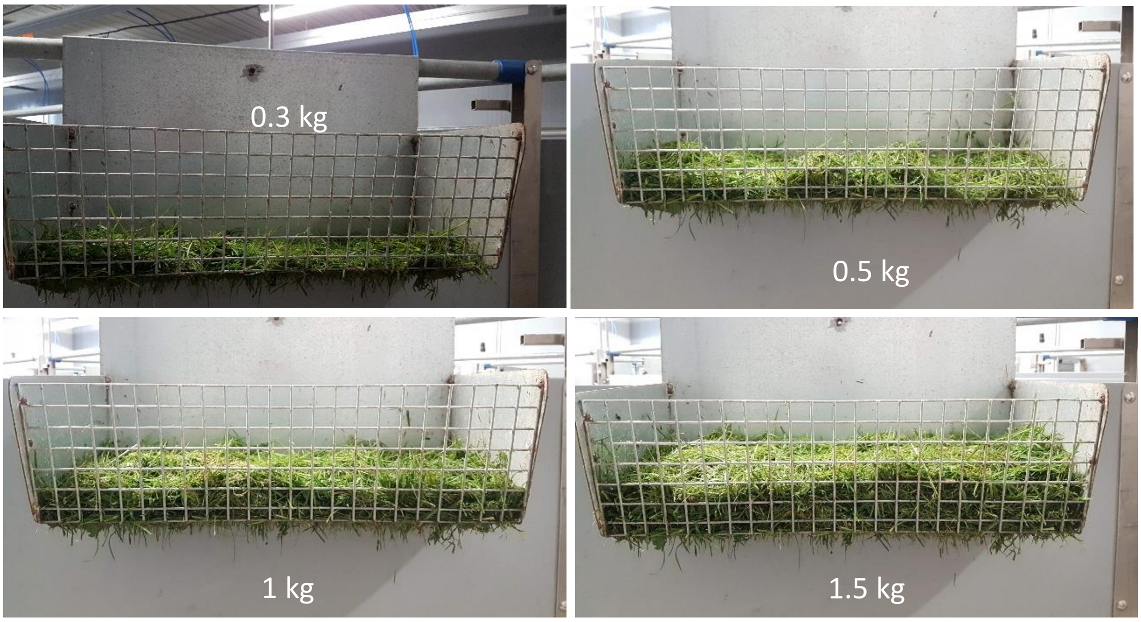

Figure 6.3. Different quantities of grass provided in the rack post weaning

The metal rack (0.59 × 0.26 × 0.25 m), which was used for dispensing the fresh cut grass, was fitted on a side of the pen 0.6 m above ground, and 0.8m from the feeder. Each mesh measured 2.5 × 2.5 cm (Figure 6.3). The provision of enrichment did not obstruct the slatted-floor area or occupy the pigs' main lying area (Figure 6.4 - 6.7).

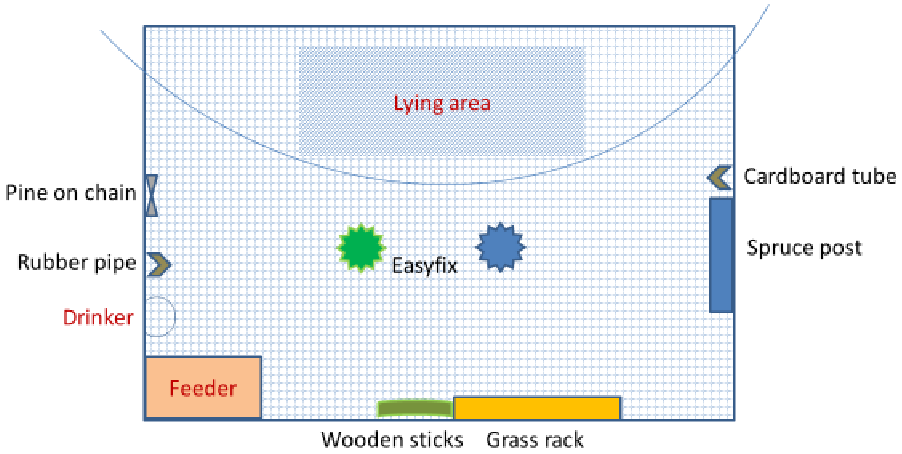

Figure 6.4. Weaner pen layout diagram

Figure 6.5. Photograph of a weaner pen

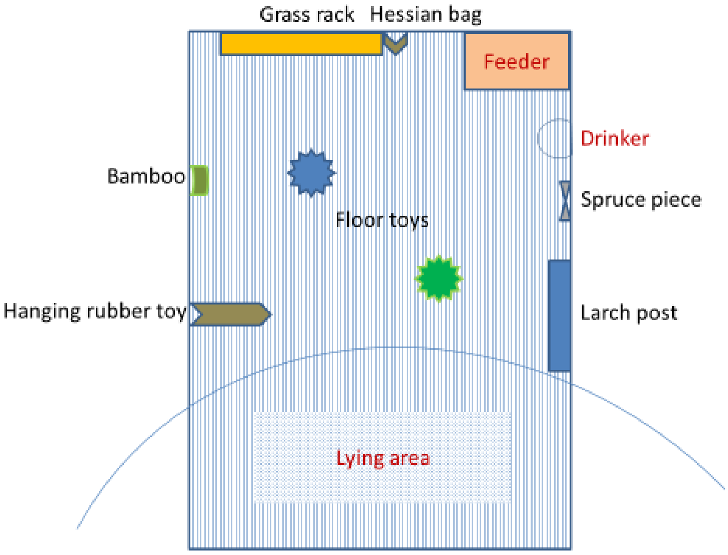

Figure 6.6. Finisher pen layout diagram

Figure 6.7. Photograph of a finisher pen

6.3.3 Measurements

All pigs were checked three times daily by the experimenter and additionally by the farm staff for any signs of tail biting, following a protocol described in Chapters 5 and 7. The individual animal identification, and details of the causes of any removals or treatments applied to pigs, either due to tail biting or other health issues, were recorded.

6.3.3.1 Enrichment

The quantity provided and replacement rate of the fresh-cut grass was recorded. The floor toys in both stages, the spruce and larch post, the spruce piece and the hanging Easyfix Astro200 provided in the finisher stage were weighed at the start and finish of the study (or whenever replaced). The replacement rate of all items was also recorded.

6.3.3.2 Pig physical measures

6.3.3.2.1 Growth

Pigs were weighed individually at weaning (D0), upon transfer to the finisher house (D49), 6 weeks into the finishing stage (D91) and before slaughter (D113). A group (pen) weight was also taken 3 weeks post-weaning (D21) and post-transfer (D70). The birth weight was only obtained for batch 3-5. The daily feed intake was taken from one week after weaning when pigs finished the starter diet.

Tail lesion, tail lateralisation, ear lesion and tear stain scores were recorded for individual pigs on a fortnightly basis.

6.3.3.2.2 Tail lesions

Tail lesions were scored using the scoring system developed by the FareWellDock consortium, as described in Chapter 4 (tail damage score – 0: no lesion, 1: bite marks, 2: open wound, 3: swollen bite wounds; tail blood score – 0: no blood, 1: black scar, 2: older red blood, 3: fresh blood. A pictorial guide can be found in appendix A in Chapter 7). The amount of tail amputation was scored on a 0-3 scale; 0: no cannibalism, 1: partly shortened longer than half of a normal undocked tail (visually estimated), 2: partly shortened shorter than half of a normal undocked tail but longer than a short-docked tail (visually estimated), and 3: shorter than the length of a short-docked tail (visually estimated).

6.3.3.2.3 Tail lateralisation

During tail scoring, if the tail was curled up, and whether it was curled towards the left side of the body or the right side of the body was recorded (Figure 6.8). If the tail stayed in the middle without side bias, it was recorded as “middle.” If the tail was hanging down or wagging so that no position can be recognised, it was recorded as missing data. Only pigs scored at least on 4 occasions were included in the analysis of tail lateralisation.

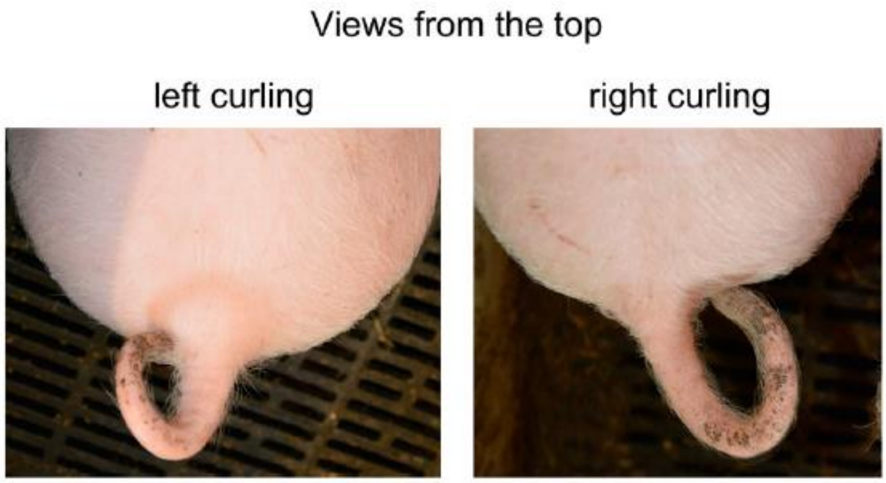

Figure 6.8. Pictorial guide of tail lateralisation from Goursot et al. (2018)

6.3.3.2.4 Ear lesions

Ear lesions were scored using the scale adapted from Telkänranta et al. (2014a) as described in Chapter 3.

6.3.3.2.5 Tear staining

Tear stain scoring was carried out using the DeBoer-Marchant-Forde Scale (DeBoer et al., 2015; Figure 6.9). The left and right eye were scored separately.

<u>0-5 Tear-Staining Scoring</u>

Tear staining scoring (0-5)	
0	No signs of any staining
1	Staining is barely detectable and area stained does not extend below the eyelid
2	Staining is obvious and area stained is approximately <50% of total eye area
3	Staining is obvious and area stained is approximately 50-100% of total eye area
4	Staining is severe, area stained is approximately ≥100% of total eye area, and area stained does not extend below the mouth line
5	Staining is severe, area stained is >100% of total eye area, and area stained extends below the mouth line

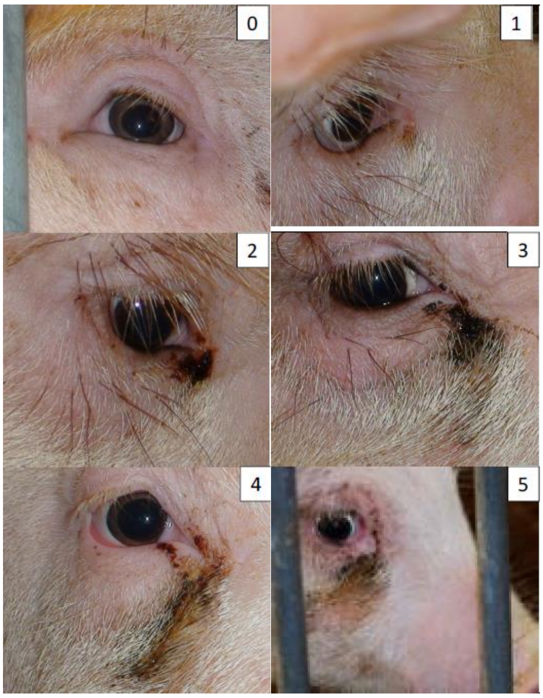

Figure 6.9. Tear-staining scoring guide by DeBoer et al., 2015

6.3.3.2.6 Tail posture

Tail posture was scanned from outside the pen every Monday, Wednesday and Friday using the protocol developed by Lahrmann et al. (2018): 0 - up (curled up), 1 - down (hanging), 2 - tucked (down and tucked into the body). During tail lesion scoring sessions, tail posture was also recorded using the same scale.

6.3.3.3 Direct behaviour observation

Direct observations were conducted using two methods; focal sampling of the enrichment, and all occurrence sampling of the pen using the ethogram adapted from Chou et al. (2019) (not included in the thesis; Table 6.4). The duration of observation for each sampling method was 5 minutes (i.e., 5 minutes on the enrichment and 5 minutes on the other behaviours). Frequency of behaviours was recorded and a bout of behaviour longer than 1 minute was counted as a new bout. The observation was carried out on each pen twice every week, with one session in the morning between 1000h to 1300h on one day and one session in the afternoon between 1500h to 1800h on a different day. Sampling days were distributed across different days of a week so that whenever possible, the same pen of pigs was not always sampled on the same day of week. During the observation, the number of pigs lying inactively for the whole 5 minutes was also recorded. Pigs were individually identified by different combinations of coloured ear tags.

Table 6.4. Ethogram used for behaviour observation

Behaviours	Description of behaviours
Enrichment directed behaviours	
Interact with the item	Any oral manipulation of the items with mouth open, manipulation of, or moving the items using the snout, or any physical contact with the item other than mouth/snout, whether standing, sitting or lying
Aggressive encounter	Biting, head-knocking or pushing over access to the device
Damaging behaviours	
Tail manipulation not at feeder (standing or lying/sitting)	Oral manipulation of the tail (tail-in-mouth) of another pig not feeding at the feeder
Tail manipulation at feeder	Oral manipulation of the tail (tail-in-mouth) of another pig which is feeding at the feeder
Ear manipulation (standing or lying/sitting)	Oral manipulation of the ear (ear-in-mouth) of another pig
Biting other parts of the body	Biting a pen mate in another region other than tail and ear, e.g. hock, flank, snout, or genital area
Belly nosing	Rubbing/manipulating a pen mate's belly/flank region with rhythmic up and down snout movement
Mounting	Putting two front legs on top of another pig
Aggressive behaviour	Pushing, head-knocking and open-mouth fighting with pen mates
Positive behaviours	
Social nosing (face)	Gentle, non-open mouth nosing on another pen mate's facial area (without reaction from the recipient) (Camerlink and Turner, 2013)
Individual play	Any scampering, pivoting, head tossing, flopping and pawing movement (Donaldson et al., 2002; Newberry et al., 1988)

6.3.3.4 Post-mortem inspection

Before pigs were sent for slaughter, coded tattoos were applied for individual identification at the slaughterhouse. The carcasses were inspected for tail damage on the processing line after scalding using the system developed by Harley et al. (2012) and the same tail amputation scoring system as described in section 6.3.3.2.2. Carcass and visceral condemnation records were obtained from the veterinarian inspectors on site. The individual carcass quality report, including cold weight, the percentage of lean meat, muscle (%), and fat (%), was retrieved from the slaughterhouse.

6.3.4 Cost analysis

The grams consumed per pig per day of the enrichment items for which weight losses were recorded (grass, wooden posts, floor toys, spruce piece and rubber hanging toy) was calculated. The grass and cardboard tubes used in the study were obtained free of charge and therefore an estimation of the market price was used for the analysis (average market price of grass silage was used in lieu of fresh cut grass since no price for fresh cut grass was available). The costs of items for which weights were unavailable were calculated using the replacement rate, and the estimated cost per piece of item. The pine block, rubber pipe and bamboo were minimally consumed during the whole study, and therefore the cost was a rough estimation as the equivalence of cost as 10 grams of pine block used, based on the pilot study (Chou et al. 2019, not included in the thesis). The total enrichment cost was calculated for 48 days in the weaner stage and 64 days in the finisher stage.

As previously stated, a parallel unrelated study took place in the same research facility during the same time period as this study, using the offspring from the shared batches of sows (Rooney et al., 2019). In that study, pigs had their tails docked, and minimal enrichment was provided (one rubber floor toy per 12 pigs in the weaner stage, and one potato bag per 12 pigs in the finisher stage. The replenishment rate of the potato bag was not recorded and therefore was calculated as one bag per pen in terms of cost. Additional enrichment, such as chains or hanging wooden pieces, was provided when tail biting was observed. The floor toy and potato bag are the same as the ones used in the current study. As all aspects of management other than enrichment provision was identical for pigs on both studies, the Teagasc Pig Production Model (TPPM, Calderón Díaz et al., 2019) was utilised to conduct a basic cost analysis comparing the profit margins between the two production scenarios ("undocked enriched," i.e. the average of three post-weaning treatments, vs. "docked barren"). The data used for comparison were the weights of pigs at weaning, transfer to the finisher accommodation, and immediately pre-slaughter, the average daily feed intake, number of weeks taken to slaughter, the kill out percentage and the cost of enrichment provision.

6.3.5 Tail biting outbreak management

The same tail biting outbreak intervention protocols described in Chapter 7 (section 2.3-2.6) were applied in the current study. The outcome of the intervention protocols will also be discussed in Chapter 7.

6.3.6 Statistical analyses

SAS Base 9.4 (SAS Institute Inc., Cary, NC, USA) was used for data analyses. The weight of enrichment consumed, the weight gain of the pigs, the pigs' feed intake, behavioural data, and carcass qualities were analysed using linear mixed models (Proc Mixed). For the weight of enrichment consumed, a logarithm transformation was used as residuals were not normally distributed. Behaviour data from individual pigs in the pen were averaged as frequencies per pig per minute, and an arcsine square root transformation was used to transform data that were not normally distributed. Detailed descriptions of the effects used in each model are listed in Table 6.5.

Enrichment use, replacement rate and removal of pigs were count data and analysed by generalised linear mixed model (with a Poisson distribution and log link function, Table 6.5).

Lesion, tear staining scores and tail posture during scoring were analysed using generalised linear mixed models (Proc Glimmix, Table 6.5), using a multinomial distribution with a cumlogit link function. Different weeks of recordings were analysed separately due to model compatibility, and the left and right eye of tear stain scores were also analysed separately (Table 6.5). Additionally, the proportion of pigs which had scores on each level of the scoring system were analysed using a linear mixed model (Proc Mixed), and an arcsine square root transformation was used when residuals were non-normally distributed. If transformations failed to generate normal distribution of residuals, generalised linear mixed models were used instead (with Poisson distribution and log link function). Post-mortem tail scores were also analysed using a generalised linear mixed model similar to lesion scores recorded alive (Table 6.5).

Tail lateralisation was analysed using methods detailed in Goursot et al. (2017), to check for lateralisation bias and a particular side bias within each pig, and a general side bias within the population. The tail bias was analysed by Glimmix using a binary distribution with a logit link function (Table 6.5). Whether tail lateralisation recorded in each session agreed with the pig's tail bias or not was further analysed by Glimmix using the same function as described above (Table 6.5).

Besides checking for treatment differences (Table 6.5) for all pens, tail scans in all pens with tail biting outbreaks were analysed separately. Two models were used: 1) tail scans within 21 days before and after the onset of outbreak were grouped into nine categories (D-21 to D-15, D-14 to D-8, D-7 to D-4, D-3 to D-1, D0 as onset of outbreak, D1 to D3, D4 to D7, D8 to D14 and D15 to D21), and 2) tail scans within a week before and after the outbreak were grouped into seven categories (D-8 to D-7, D-6 to D-4, D-3 to D-1, D0 as onset of outbreak, D1 to D3, D4 to D6 and D7 to D8). This was to compare the long- and short-term effect of an outbreak on tail posture. The day relative to the onset of the outbreak, and batch, were included as fixed effects, pen within batch as a random effect, and day of tail scans as the repeated effect. Tail postures recorded during each outbreak were also analysed on an individual basis, to compare tail posture between pens with and without an outbreak, and one week before and after the onset of outbreak within the same batch (at the same age). In this model outbreak or control (no outbreak), day relative to outbreak and their interaction were included as fixed effects, pen was included as a random effect, and day of tail scans was included as the repeated effect.

6.3.7 Ethical statement

This study was approved by the Teagasc Animal Ethics Committee (TAEC163-2017). Sample size calculation was estimated using The GLMPOWER Procedure in SAS 9.4 based on a previous study (Ursinus et al. 2014) with a tail lesion difference of 0.9, an estimated standard deviation of 0.05, a significance level at $P < 0.05$ and a power of 0.8 to test differences in a 2×3 factorial design.

Table 6.5. Detailed description of statistical analyses using the Mixed and Glimmix model

	Unit	Analytic unit	Model[1]	Fixed effects	Repeated effect
Weight of enrichment	Kg	Pen (N = 48)	Mixed	Treatment, batch	*Day (Grass)
Enrichment use and replacement	Day	Pen (N = 48)	Glimmix	Treatment, batch	N/A
Weight gain of pigs	Kg (average daily gain)	Individual (N = 576)	Mixed	Treatment, batch, sex	N/A
Feed intake	Kg (average daily feed intake)	Pen (N = 48)	Mixed	Treatment, batch	N/A
Lesion scores	Ordinal scores	Individual (N = 576)	Glimmix	Treatment, batch, sex	N/A
	Percentage of scores	Pen (N = 48)	Mixed/ Glimmix	Treatment, batch, week	Week
Behavioural data[2]	Frequency/pig/min	Pen (N = 48)	Mixed	Treatment, batch, week, session, number of pigs (covariate)	Session within week
Carcass qualities	Percentage	Individual (N = 576)	Mixed	Treatment, batch, sex	N/A
Post-mortem tail scores	Ordinal scores	Individual (N = 576)	Glimmix	Treatment, batch, sex	N/A
Tail scans	Proportion of scores	Pen (N = 48)	Mixed	Treatment, batch, week	Day
Tail lateralisation	Left/right	Individual (N = 576)	Glimmix	Treatment, batch, sex, week, tail damage score, tail blood score	Week
	Agree or not	Individual (N = 576)	Glimmix	Tail damage score, tail blood score	Week

[1] Pen within batch was included in all models as a random effect.

[2] Enrichment interaction in the weaner and finisher stage was analysed separately.

6.4 Results

In total, 76 pigs were temporarily removed as tail biting victims (18 from "High" pens, 39 from "Medium" pens and 19 from "Low" pens; six pigs were removed twice and one pig removed three times), 22 pigs removed as tail biters based on the definition in the tail biting outbreak intervention protocol (six from "High" pens and 16 from "Medium" pens), and 4 pigs had antibiotic injections in their home pen. There were 23 pigs removed from the study prematurely, out of which 2 pigs needed to be euthanised due to whole body and hind leg paralyses that may have been associated with tail biting due to previous record of tail amputation. Others were removed due to other health issues, including one case of tail necrosis in a pen without any history of tail biting, hernia, respiratory failure, lameness and sudden deaths. The removals and health issues of the pigs were not affected by treatment ($P > 0.05$). There were 14 tail biting outbreaks from 12 pens (2 pens had recurring outbreaks) and no difference was found between treatments (four outbreaks in "High" pens, five in "Medium" pens and three in "Low" pens). The average length of the outbreaks was 13.3 ± 1.2 days.

6.4.1 Enrichment consumption and cost

In terms of the weight of different enrichment items consumed, there was only an effect of treatment on the consumption of grass; "High" enrichment replenishment rate pigs consumed more grass than "Medium" and "Low" pigs ("High" 90.5 ± 13.5 vs. "Medium" 54.7 ± 11.4 and "Low" 58.4 ± 8.8 g/day/pig; $F = 31.67_{(38.1,\ 2)}$, both at $P < 0.001$). In the weaner stage, pre-weaning "Barren" pen pigs tended to consume more of the rubber floor toys than "Enriched" pen pigs (0.029 ± 0.005 vs. 0.017 ± 0.004 g/pig/day; $F = 4.14_{(32.57,\ 1)}$, $P = 0.05$), but there was no difference in any other item. Neither was there a difference between treatments in the replacement rate of the enrichment items. The estimated cost of each item in each treatment is listed in Table 6.6.

Table 6.6. Estimated cost of all enrichment items used in the study

		Enrichment replenishment rate					
	Unit cost (€)	High		Medium		Low	
		Use[1]	Cost (€)[1]	Use	Cost (€)	Use	Cost (€)
Grass (g)[2]	0.00003	90.517†	0.003†	54.702†	0.002†	58.361†	0.002†
Weaner							
Rubber floor toy (g)	0.016	0.018†	0.0003†	0.021†	0.0003†	0.018†	0.0003†
Spruce post (g)	0.001	0.188†	0.0003†	0.246†	0.0003†	0.295†	0.0004†
Cardboard tube (piece)[3]	0.124	0.417	0.052	0.385	0.048	0.292	0.036
Wooden sticks (2 pieces)	0.732	0.172	0.126	0.151	0.111	0.151	0.111
Pine block (use)[4]	0.015	0.083	0.001	0.083	0.001	0.083	0.001
Rubber pipe (use)[4]	0.015	0.083	0.001	0.083	0.001	0.083	0.001
Finisher							
Larch floor toy (g)	0.015	0.400†	0.006†	0.473†	0.007†	0.415†	0.006†
Spruce floor toy (g)	0.015	0.489†	0.007†	1.267†	0.019†	1.043†	0.016†
Larch post (g)	0.001	0.204†	0.0002†	0.189†	0.0002†	0.168†	0.0002†
Spruce piece (g)	0.001	0.338†	0.0003†	0.406†	0.0004†	0.477†	0.0005†
Rubber hanging toy (g)	0.022	0.051†	0.001†	0.006†	0.000†	0.025†	0.001†
Sack (piece)	1.000	0.115	0.115	0.089	0.089	0.109	0.109
Bamboo (use)[4]	0.015	0.083	0.001	0.083	0.001	0.083	0.001
Total (production cycle)[5]			1.599		2.203		1.982

[1] For all items that were recorded by weight loss (g), the unit for use was g/pig/day (cost: €/pig/day, indicated with †), and for all other items the unit was per pig per weaner or finisher stage

[2] The grass in the current study was collected free of charge, so the estimation used the current average grass silage price at €30/tonne.

[3] The cardboard tubes in the current study were collected free of charge, so the estimation used the market price of similar products.

[4] The pine block and rubber pipe were minimally consumed, and the weight loss is not available. The rough estimation is based on the cost of 10g of the pine block consumed per use per batch. The bamboo was obtained for free and the surrogate cost was unattainable and therefore the same estimation as the pine block was used.

[5] The total cost per pig for each treatment was calculated with 48 days in the weaner stage and 64 days in the finisher stage.

6.4.2 Growth

Pre-weaning treatment did not have an effect on ADG in any stage. Weaning weight and moving weights were the same between treatments. Post-weaning "High" pigs had a greater average daily gain (ADG) than "Low" pigs during the finisher stage, and the difference was greater during the first six weeks than the whole nine weeks (Figure 6.10). There was no difference in ADG during the weaner stage, and thus over the entire production cycle, weight gain tended to be higher in "High" pigs (P = 0.06). No difference was found in average daily feed intake and feed conversion ratio between treatments in the weaner or finisher stage. The duration of finishing did not differ between treatments, but female pigs took longer to reach slaughter weight than male pigs ($P < 0.01$).

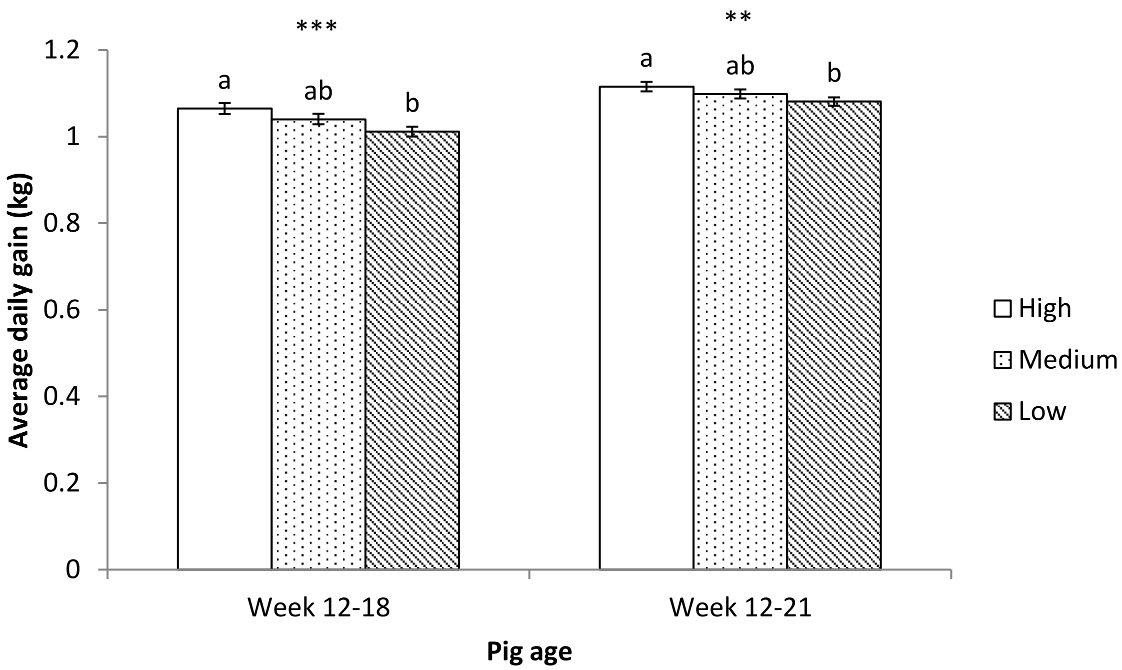

Figure 6.10. Pigs' average daily gain (kg) in the finisher stage between post-weaning treatments during 12 – 18 weeks of age (first 6 weeks in the finisher stage, left) and during 12 – 21 weeks of age (the whole finisher stage, right). Significant differences are indicated by different letters between treatments during the same age after Tukey-Kramer adjustment. ** $P < 0.01$ *** $P < 0.001$

6.4.3 Lesion and tear staining scores, and tail posture

There was no effect of treatment on tail lesion scores either in terms of damage or blood scores. Differences between weeks in terms of the percentage of different severities of scores were found. The percentage of score 0 ($P < 0.001$ for both damage and blood) and score 2 & 3 combined (moderate to severe, $P = 0.01$ for damage and $P = 0.03$ for blood) differed between weeks (Figure 6.11). A higher probability of tail posture scored "0" (i.e. curled up) when tail lesions were lower, both in terms of tail damage score and tail blood score ($P < 0.001$, Figure 6.12).

For ear lesions, pre-weaning "Enriched" pigs had a higher proportion of score 0 than "Barren" pigs (0.071 ± 0.006 v's 0.056 ± 0.006; $F = 4.2_{(38.6,1)}$, $P = 0.04$). During the seven lesion scoring sessions, 93.44 ± 0.51% of pigs showed curled-up tails, but "Enriched" pigs had a lower proportion of pigs showing down and tucked tails than "Barren" pigs (0.04 ± 0.01 v's 0.07 ± 0.01; $F = 4.67_{(50.41,1)}$, $P = 0.04$). No difference in tear stain scores was found between treatments.

At the end of the study, 72.57% of pigs had intact tails without amputation, 23.44% had tail amputation score 1 (meaning that more than half the tail remained; >7cm) and 0.69% were with more severe amputated tails (score 2; less than half the tail remained; 3-7cm).

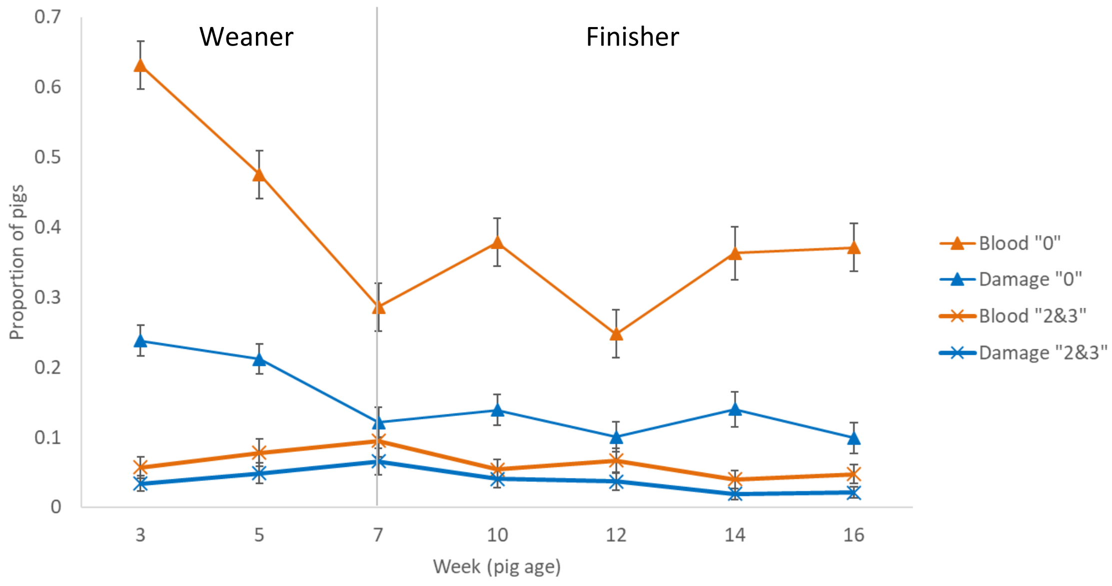

Figure 6.11. Percentage of pigs with no lesion (score 0) and moderate to severe lesions (score 2 and 3 combined) over the experimental weeks (tail damage score – 0: no lesion, 1: bite marks, 2: open wound, 3: swollen bite wounds; tail blood score – 0: no blood, 1: black scar, 2: older red blood, 3: fresh blood).

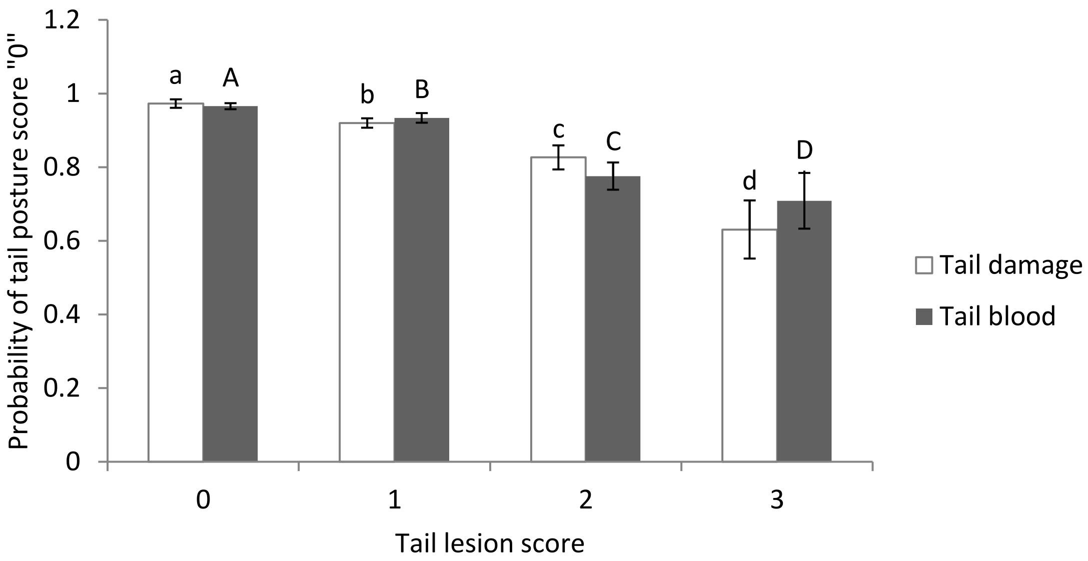

Figure 6.12. Probability of tail posture being scored “0” (curled-up) for tail lesion scores of different severities ($P < 0.001$). (Tail damage score – 0: no lesion, 1: bite marks, 2: open wound, 3: swollen bite wounds; tail blood score – 0: no blood, 1: black scar, 2: older red blood, 3: fresh blood). Different letters indicate differences between levels of damage (small letters) or blood (capital letters) scores.

6.4.4 Tail lateralisation

The population showed a tail lateralised bias, meaning that most pigs were consistent in which side their tail was curled ($X^2_{(1,\, n = 1084)}$ = 200.20, P < 0.001, Figure 6.13), and with slightly more pigs right than left biased ($X^2_{(1,\, n = 971)}$ = 4.38, P = 0.04, Figure 6.13), but no overall right-side bias (i.e. when comparing the number of right biased pigs to the rest of the population including left-biased and non-biased, P > 0.1). The side bias of the tail was not affected by the treatments. Among pigs which showed a tail bias (left or right), tail lesion scores did not have an effect on their side bias, but when the tail score increased, the probability of the tail lateralisation to be inconsistent with the default tail bias was higher (tail damage P = 0.01 and tail blood P < 0.001, Figure 6.14). When only comparing left, right and the middle position scored, excluding the missing scores, there was no significant difference, and whether the tail was amputated or not did not affect tail bias. When unbiased pigs were excluded, female pigs showed a lower probability to be left-biased compared to males (0.42 ± 0.04 vs. 0.49 ± 0.04, F = $18.77_{(3492,1)}$, P < 0.001) and also a mild tendency to be more right-side biased in general (P = 0.09).

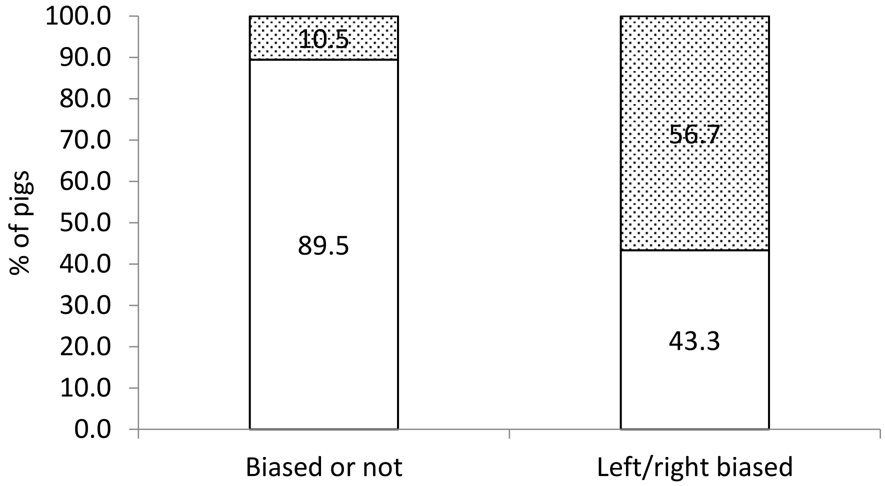

Figure 6.13. Left: percentage of pigs with a tail bias (white block) or not (dotted block), P < 0.001. Right: the percentage of pigs with left tail bias (white block) and right tail bias (dotted block), P = 0.04.

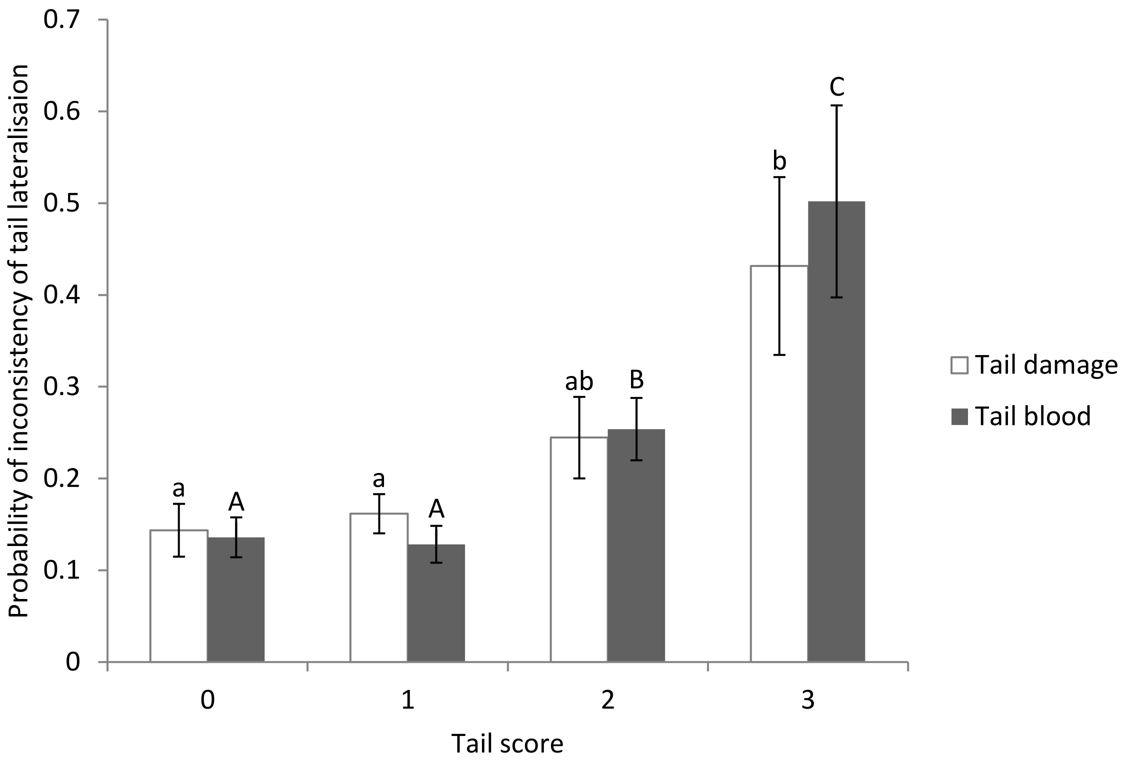

Figure 6.14. The probability of inconsistency of tail lateralisation relative to default tail bias, when tail lesions were scored at different severity levels (tail damage score – 0: no lesion, 1: bite marks, 2: open wound, 3: swollen bite wounds; tail blood score – 0: no blood, 1: black scar, 2: older red blood, 3: fresh blood). Different letters indicate differences between levels of damage (small letters) or blood (capital letters) scores.

6.4.5 Tail posture scans in relation to tail biting outbreaks

In pens with tail biting outbreaks, the proportion of pigs with tucked tails increased about 3 days before D0 of the outbreak (Figure 6.15 and 6.16). The higher proportion of tails tucked continued 2-3 weeks after the onset of the outbreak, before returning to the pre-outbreak level (D-3 to -1, Figure 6.16). Compared to pens without outbreaks within the same batch (i.e. at the same age), the proportion of pigs with tucked, or down and tucked, tails was higher in pens with outbreaks (Table 6.7). The proportion of tucked tails was more sensitive in picking up differences between outbreak and non-outbreak pens compared to both down and tucked tails combined. There was an interaction between whether an outbreak occurred and the number of days before it did; this showed that the difference in the proportion of tucked tails usually began to appear around 3-4 days before outbreak onset.

Table 6.7. Proportion of tucked or down and tucked tails between control (no outbreak) and outbreak (OB) pens for each tail biting outbreak recorded

	Proportion of tucked tails			Proportion of down & tucked tails		
OB	Control pens	Outbreak pen	*P* value	Control pens	Outbreak pen	*P* value
1	0.012	0.121	< 0.01	0.147	0.299	< 0.01
2	0.029	0.076	< 0.01	0.275	0.376	NS
3	0.004	0.184	< 0.001	0.173	0.362	< 0.01
4	0.008	0.267	< 0.001	0.096	0.292	0.01
5	0.022	.	0.04	0.182	.	NS
6	0.020	0.108	NS	0.145	0.303	NS
7	0.014	0.067	0.03	0.120	0.189	NS
8	0.004	.	< 0.001	0.094	.	< 0.001
9	0.021	0.060	NS	0.166	0.240	NS
10	0.018	0.360	< 0.001	0.108	0.521	< 0.01
11	0.008	0.305	< 0.001	0.079	0.455	< 0.001

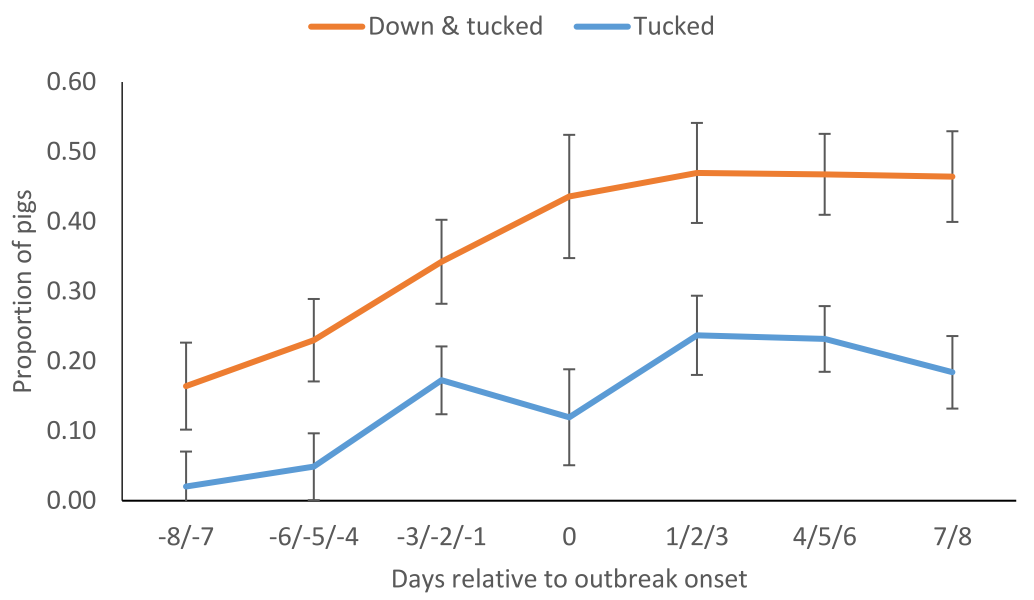

Figure 6.15. Proportion of tucked (score 2, blue line), and down and tucked (score 1 and 2 jointly, orange line) tails, one week before and after the onset of a tail biting outbreak. Tail posture was scored as 0: up (curled up), 1: down (hanging), 2: tucked (down and tucked into the body).

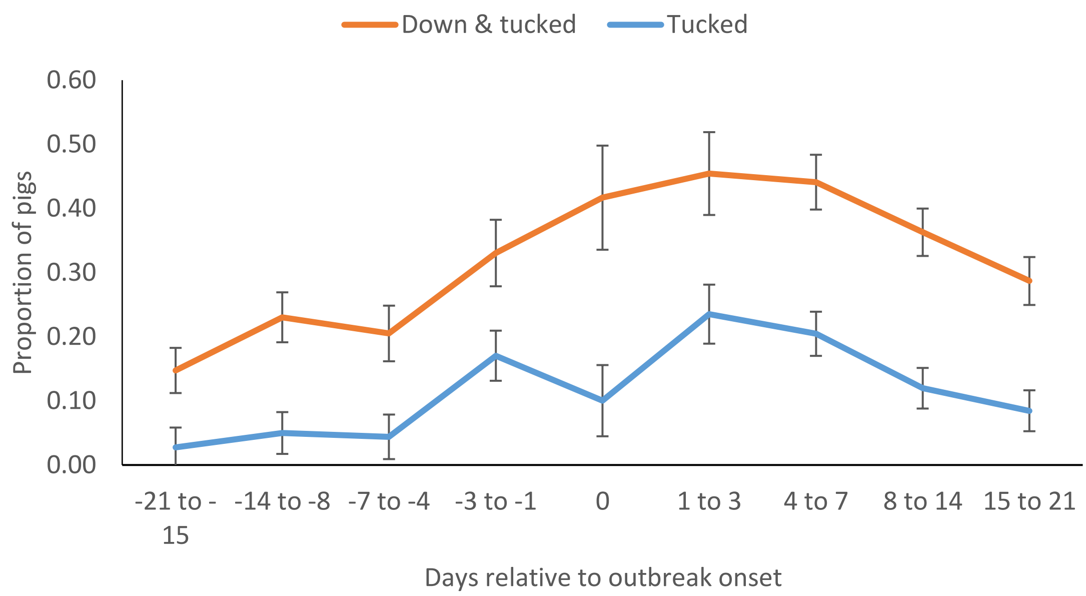

Figure 6.16. Proportion of tucked (score 2, blue line), and down and tucked (score 1 and 2 jointly, orange line) tails three weeks before and after the onset of a tail biting outbreak. Tail posture was scored as 0: up (curled up), 1: down (hanging), 2: tucked (down and tucked into the body).

6.4.6 Behaviour

There was no difference in any behaviour observed between pre-weaning treatments. Over the entire post weaning period, "High" pigs performed damaging behaviours (tail/ear biting, other biting, belly-nosing, mounting and aggressive behaviours) less frequently than "Low" pigs (0.0101 ± 0.0004 vs. 0.0120 ± 0.0004, $F = 5.14_{(38,2)}$, $P = 0.01$). No other difference in behaviours was found between post-weaning treatments. Both general behaviours and the amount of interaction with the enrichment showed a gradual declining trend, while the proportion of pigs lying inactive increased, as pigs grew older (Figure 6.17). The total amount of behaviours observed and the proportion of pigs inactive did not differ between treatments.

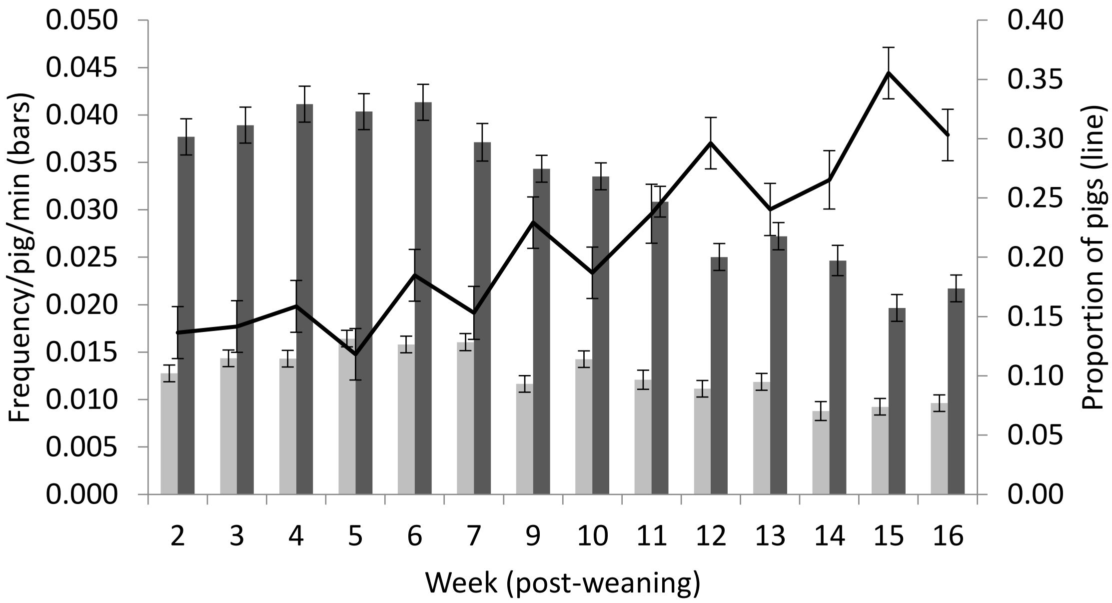

Figure 6.17. Activity level over time based on A) general behaviours combined (light grey bars, as frequency/pig/min, $P < 0.001$) B) total enrichment interactions (dark grey bars, as frequency/pig/min; week 2-7 P > 0.1; week 9-16, $P < 0.001$) and C) proportion of pigs lying inactively (black line, $P < 0.001$).

The overall amount of interaction with all enrichment items combined did not differ between treatments, but pigs showed a preference for different items, and similar preferences were found in both the weaner and finisher stage (Figure 6.18). Grass was the most preferred enrichment; during the weaner stage, more interactions with grass were observed in “High” pigs than “Medium” or “Low” pigs (P < 0.001, Figure 6.19), although this was not the case in the finisher stage (Figure 6.20). On the contrary, the total interaction with all items other than grass was greater in “Low” than “High” (P = 0.02, Figure 6.19) during the weaner stage, and there was also no difference in the finisher stage (Figure 6.20). The enrichment that was the next preferred after grass in the weaner stage, the wooden stick, was used more frequently by “Barren”-“Low” pigs than “Barren”-“High” pigs (0.008 ± 0.001 v’s 0.005 ± 0.001, $F = 3.25_{(555,3)}$, P = 0.02).

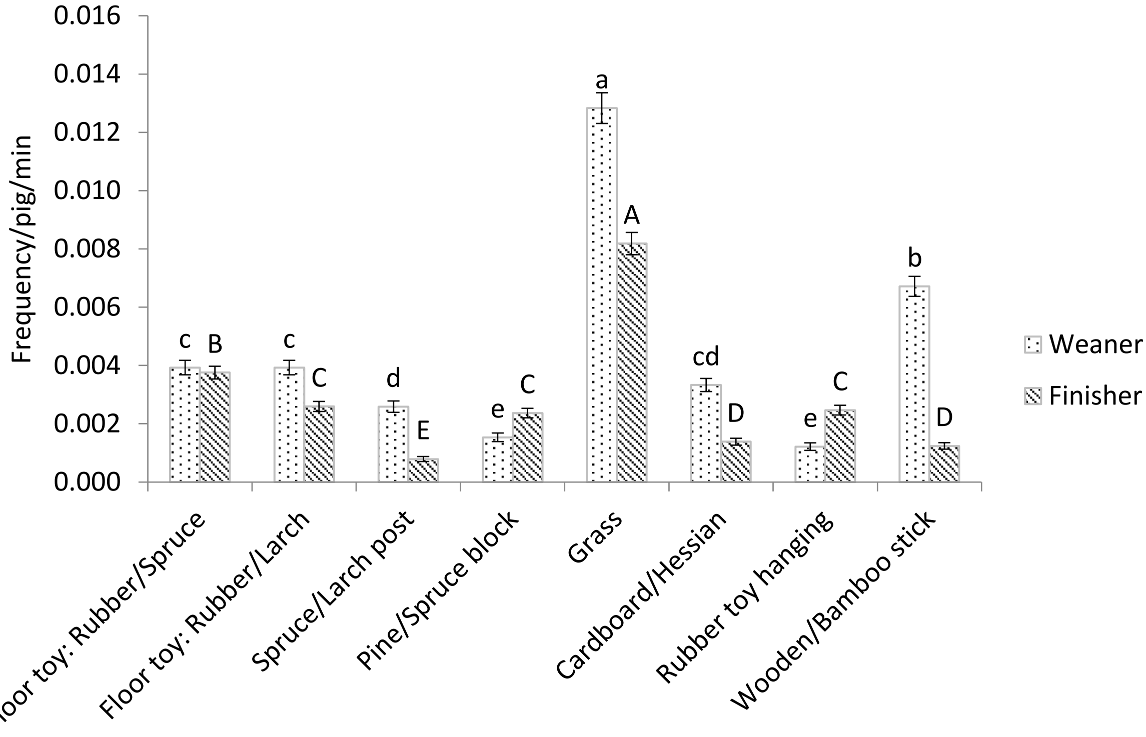

Figure 6.18. Interaction of different items in the weaner and finisher stage. Different small letters denote differences between items in the weaner stage, and capital letter for the finisher stage, after Tukey-Kramer adjustment.

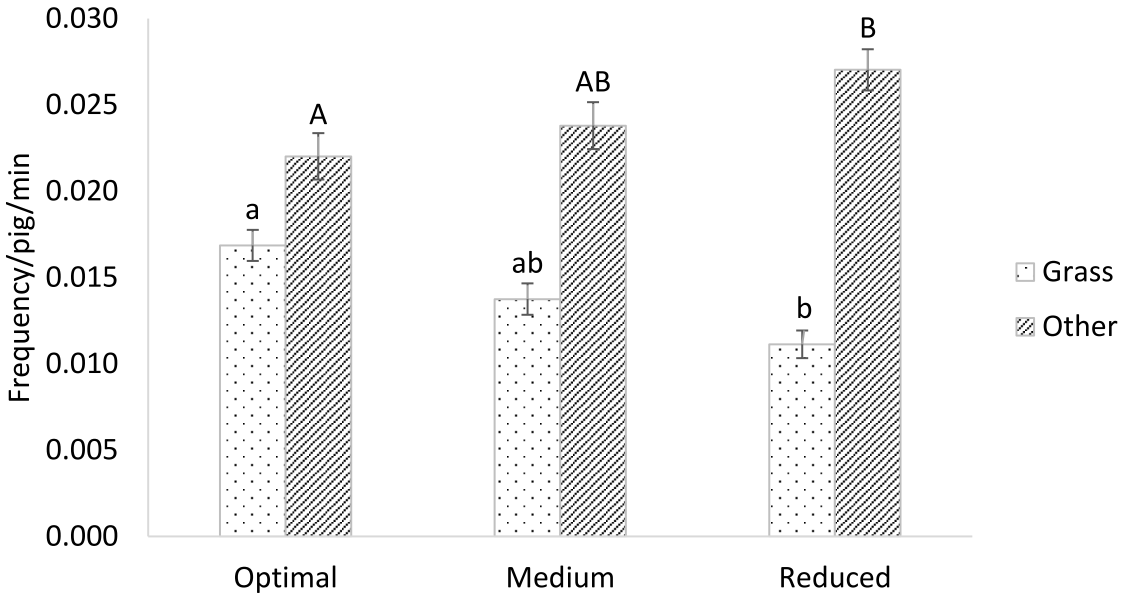

Figure 6.19. Frequency of interaction with grass and all other items between treatments in the weaner stage. Different small letters denote differences in grass interaction (*P* < 0.001), and capital letters denote differences in interactions with other items between treatments (*P* = 0.02). Differences were indicated after Tukey-Kramer adjustment.

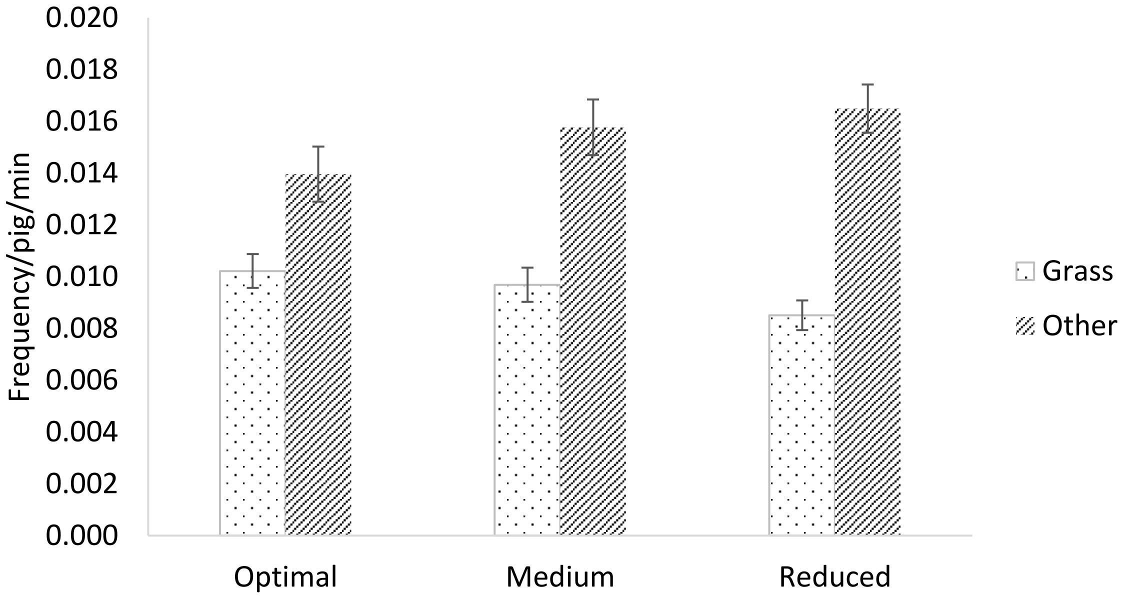

Figure 6.20. Frequency of interaction with grass and all other items between treatments in the finisher stage. No difference between treatments was found (*P* > 0.1).

6.4.7 Post-mortem examinations

No difference was found between treatments in any post-mortem measure (tail lesions, level of tail amputation, the presence or absence of tail amputation, cold weight, and the percentage of lean meat, muscle and fat). Female pigs had lower cold carcass weights than male pigs (81.92 ± 0.47 vs. 83.28 ± 0.47 kg, $F = 5.5_{(539,1)}$, $P = 0.02$).

6.4.8 Cost analysis

The descriptive data from the two studies are listed in Table 6.8. These data were entered into the TPPM, and with all other required data (using the TPPM theoretical model farm listed in Calderón Díaz et al., 2019) kept identical between the two scenarios. The theoretical model farm had a herd size of 775 sows, and produced 26.5 pigs per sow/year. These number were used to calculate the annual enrichment cost, which was €39,601 for the "undocked enriched" scenario and €2,007.20 for "docked barren." However, the model showed that "undocked enriched" generated a net margin of €9.25 per pig compared to €4.88 for "docked barren" due to a higher slaughter weight, a lower finisher feed intake and a better kill out percentage, albeit with a slightly longer time to finish.

Table 6.8. Data obtained for comparison between the two production scenarios

	Undocked enriched	**Docked barren**
Weaning weight (kg)	7.09	7.00
Transferring weight (kg)	36.94	32.76
Slaughter weight (kg)	110.94	103.4
Average daily feed intake – weaner (kg)	1.06	0.89
Average daily feed intake – finisher (kg)	2.34	2.39
No. weeks taken to slaughter	20.85	20.14
Kill out percentage (%)	74.51	73.60
Enrichment cost (€/pig/production cycle)	1.93[†]	0.10[*]

[†] The enrichment cost in the current study was the average of three enrichment treatments

[*] The basic enrichment used in the "docked barren" study was one rubber floor toy during the weaner stage and one piece of hessian sack in the finisher stage. Due to the unavailability of the enrichment consumption from that study, the same quantity calculated in the current study was used instead.

6.5 Discussion

This study investigated how both early exposure to enrichment and different management strategies for post-weaning enrichment materials could influence the outcome of tail biting in, and performance of, undocked pigs, in fully-slatted systems. To the best of the author's knowledge, this is a first attempt to use multiple point-source enrichment items, only varying the replacement rate, to investigate tail biting outcomes in undocked pigs on fully-slatted floors. Although tail biting occurred in all treatments, the level of biting was substantially reduced compared to the results from the previous chapter (**Chapter 5**). No difference in lesion scores was found between post-weaning treatments, but pigs enriched pre-weaning had slightly lower ear lesion scores. Pigs with a reduced enrichment replacement rate post weaning performed more damaging behaviours, but did not experience more tail biting outbreaks. Thus, provision of multiple types of enrichment, which were replaced as soon as they were depleted, was effective in generating pigs' sustained interest and also promoted pigs' growth in the long term. The results demonstrate the feasibility of using slat-compatible enrichment with a reasonable stocking density (0.52m^2 for growers up to around 30kg and 0.8 m^2 for finishers up to around 110kg) to reduce the risk of tail biting in undocked pigs, with a less labour-intensive strategy, in a cost-effective way.

6.5.1 Overall level of tail biting

Compared to the previous chapter (**Chapter 5**), the negative effects of tail biting were reduced in terms of the number of tail biting outbreaks, the length of outbreaks, the amount of pigs that needed to be temporarily removed due to tail biting events, and the level of tail amputation in pigs. Although sporadic tail biting still occurred, and 14 tail biting outbreaks were recorded, all but one of the pigs removed for outbreak control were reintroduced back to their home pens successfully. A detailed comparison of the tail biting outbreaks over the two studies will be discussed in the next chapter (**Chapter 7**).

6.5.2 Effect of pre-weaning exposure to enrichment

6.5.2.1 Growth

Whether or not pigs were enriched in the pre-weaning stage did not influence average daily gain (ADG) at any stage. Likewise, other studies have also shown that post-weaning enrichment has a greater effect on the weight gain of pigs than early experience (Munsterhjelm et al., 2009; Oostindjer et al., 2010; Telkänranta et al., 2014b). Brajon et al. (2017) found pre-weaning enrichment provision only increased weaners' weight gain immediately post-weaning, which again suggests a transient effect compared to post-weaning treatments.

6.5.2.2 Physical scores and behaviour

The effect of pre-weaning exposure to enrichment was not very evident in the current study, only contributing to a slight reduction in both ear lesion scores and downward tail postures. Ear lesions can be caused by ear biting and ear necrosis, but very little is understood regarding their causes and factors (Diana et al., 2019). Pre-weaning enriched pigs may be more accustomed to biting enrichment and therefore perform reduced ear biting at early stages post-weaning, when ear necrosis was commonly reported (Diana et al., 2019). However, no difference in ear biting behaviour was found between pre-weaning treatments in the current study.

Downward tail postures are recognised as a reaction to tail-directed behaviours (Lahrmann et al., 2018; Mona Lilian Vestbjerg Larsen et al., 2018), and this was demonstrated by an increase in the proportion of tucked tails before and after the tail biting outbreaks observed in this study. However, although "Enriched" pigs had fewer tucked tails scored over the course of the study, there was no effect of pre-weaning treatment on tail lesions or tail biting behaviours. Additionally, it is possible that tail posture scored inside the pen may be more affected by the disturbance of human presence than the status of the pigs at the time of scoring, and thus be less consistent as an indicator of tail damage. Tail posture has been found to be associated with emotional state and a curly tail is considered a default position without the effect of external stimuli (Reimert et al., 2013). Enriched pigs could be more used to the presence of the experimenter due to the placement and replacement of enrichment items pre-weaning, and therefore slightly less disturbed by the experimenter during lesion scoring.

It is important to note that since the farrowing pens had fully-slatted floors, the enrichment items provided to the piglets were all suspended, and not a bedding substrate. This may be the reason why only a limited number of effects were found, contrary to the positive effects in studies which used loose substrates as enrichment during the suckling stage (Day et al., 2002; Munsterhjelm et al., 2009; Telkänranta et al., 2014b). Yang et al. (2018) did find that hanging toys and ropes during the suckling stage increased piglets' play behaviour as much as pieces of wood bark provided in a box at a fixed location, but in the current study, behaviours in the suckling stage were not recorded. Therefore, it is unknown if the enrichment had any effect on piglet behaviour. On the other hand, (Oostindjer et al., 2011) found no effect of pre-weaning provision of wood shavings, peat and straw on pig's post-weaning manipulative behaviours, but a more influential factor was whether the sow was confined or loose. This suggested that the influence of early life experience on the development of damaging behaviours may entail more than just environmental enrichment. Social environment such as piglet-sow interactions, and inter-litter socialisation, should also be considered, as studies have suggested early socialisation reduces aggression at mixing (Camerlink et al., 2018), and thus could help to reduce overall stress levels. Based on the current results, the effect of early exposure to point-source enrichment has only a minor effect on the later life of pigs.

6.5.3 Effect of post-weaning enrichment management

6.5.3.1 Enrichment consumption

"High" pigs consumed the most grass post-weaning, which was due to the highest replenishment and access to grass. By contrast, "Medium" pigs did not consume more grass than "Low" pigs. This may be due to the replenishment strategy which for "Medium" pigs was once daily, and if the grass was not consumed completely during inspection, it was not replenished. This also showed that a daily small ration would result in the same amount of grass consumed as a small ration on three days per week. In terms of management, a daily routine may be easier to incorporate into habitual practice than on three days per week, but further assessment of labour input is still needed to determine if three days per week would be more economical. In any case, the results showed that either strategy did not differ in terms of the quantity of grass actually consumed.

6.5.3.2 Growth and carcass quality

There was an increase in ADG in the finisher stage when pigs received the high enrichment replenishment compared to the medium and low treatment, albeit with no difference between treatments in terms of feed efficiency. The positive effect of post-weaning straw provision on feed efficiency has been reviewed extensively. However, point-source items and substrates provided via dispensers have not seemed to affect growth in previous studies (Averós et al., 2010; van de Weerd and Day, 2009). The present study used a combination of loose substrates in dispensers, along with numerous other items that are biologically relevant for pigs, which could have enhanced the positive effect of enrichment to stimulate growth. Similar to what we found, Holinger et al. (2018) reported that when pigs were fed grass silage, there was no effect on the duration to slaughter, slaughter weights or carcass traits. However, they found grass silage reduced the prevalence of gastric ulcers in pigs. In our study, “High” pigs consumed more grass in the weaner stage which may have improved their gastric health and therefore weight gain, although without post-mortem examinations, it is not conclusive why high enrichment replenishment improved ADG in pigs. Further research is needed to explore the benefit of fresh grass to pigs’ gastric health and its possible contribution to other growth parameters.

Although there was no difference in finishing duration between treatments, 50% of the pigs reached slaughter weight (114.47 ± 0.48kg) at 20 weeks of age, which is much shorter than the average finishing length in Ireland, of around 25 weeks from birth (McCutcheon, 2018). The shorter production period has positive implications for reducing production costs. No difference was found in carcass quality between treatments, which is similar to what previous studies have reported (van de Weerd et al., 2006; van de Weerd and Day, 2009). The higher finisher weight gain in “High” pigs and the overall shorter time required to reach slaughter weight both highlight that the benefits of providing sufficient quantity and quality of environmental enrichment are not limited to improving pigs’ welfare but also promoting pigs’ performance.

6.5.3.3 Physical scores and behaviour

In the current study, the main difference in enrichment use between post-weaning treatments was the amount of grass provided, and how often other destructible and therefore depletable items were replaced. Pigs with the low rate of replenishment received and consumed less grass and sometimes had fewer enrichment items available in the pen. They performed more damaging behaviours combined than “High” pigs, although no difference in tail lesion scores or tail biting behaviour alone was found. There has been very little previous research which used the same type(s) of enrichment and compared different amount or replenishment frequency on tail biting outcome, and most such studies compared different quantities of loose straw provision. According to Day et al. (2002), when different amounts of loose straw were provided, the effect on damaging behaviours was only different between pigs with or without straw, but not between different quantities given. However, Pedersen et al. (2014) found a linear decrease in oral manipulation towards pen mates in relation to the amount of uncut straw provided. Although it is difficult to compare loose straw provision on the floor with the elevated grass dispenser used in this study, the results suggested that when the same enrichment was provided, the quantity of provision can still affect the outcome of damaging behaviours. In terms of point-source enrichment items, a meta-analysis suggested that when these are provided in an adequate quality and quantity, negative social behaviours in pigs can be reduced (Averós et al., 2010). This is evidenced by the significant reduction in the overall risk of tail biting in the current study, compared to the previous chapter (**Chapter 5**) when only one point-source enrichment item was provided for 14 pigs.

Pigs showed a preference for grass, suggesting it was the most valuable enrichment provided, similar to the results of the pilot study (Chou et al., 2019, not included in the thesis). This result is in agreement with other studies where loose materials were preferred over point-source items (Guy et al., 2013; van de Weerd et al., 2003; van de Weerd and Day, 2009). “High” pigs consumed a higher quantity of grass and had the highest interaction with grass in the weaner stage. In a study which compared a different number of racks (containing the same amount of chopped straw), greater levels of interaction were also found in groups with more racks, and subsequently more straw available at the same time, although the overall quantity of straw consumed was not reported (Zwicker et al., 2012). This showed that as a higher quantity of loose materials is available in the pen, it generates more interaction and consumption. In contrast, “Low” pigs interacted with all items other than grass more than “High” pigs. Scott et al. (2006b) found that when a hanging toy was provided in a barren environment, it attracted more interactions from the pigs than in a straw-bedded pen. When the more preferred resource is absent, pigs might divert their attention to less favourable items. On the other hand, if point-source items possess properties such as being chewable and ingestible, they can be attractive to pigs even in the presence of more favoured items (van de Weerd et al., 2003). Therefore, provision of a variety of biologically relevant enrichment items as well as loose material could encourage more interactions from pigs when the loose material is depleted. Other than grass, weaners interacted most with hanging wooden sticks, followed by the rubber floor toy, spruce post and hanging cardboard. The finishers showed a similar preference to the wooden floor toys, followed by the hanging spruce block and rubber toy. It has commonly been thought that point-source items are more preferred by the pigs when suspended compared to loose on the floor, due to difficulties in maintaining cleanliness when on the floor (Averós et al., 2010). However, in the current study, this was evidently not the case. The floor toys used in the current study were designed to prevent them from being soiled easily, and thus their attractiveness was not hampered by a lack of hygiene. If hygiene standards are good, and the items on the floor have some properties that pigs prefer (e.g. being destructible, deformable or chewable), then they could be extremely favourable to pigs, as they can facilitate a head down, rooting action, which is part of their natural behaviour repertoire.

The interaction with the enrichment showed a declining trend over time. However, this could be due to the fact that pigs became less active in general as they aged, as shown in the proportion of pigs recorded lying inactively. A combination of multiple enrichment items with different biologically relevant properties to the pigs present in the pen might have sustained pigs' interest for longer and diminished habituation in the current study, similar to what Guy et al. (2013) found.

6.5.4 Cost

The "High" treatment did not result in the highest enrichment cost overall, partly due to the higher consumption of grass and lower consumption of other consumable items, which may be more expensive per unit than the estimation of loose materials used in the current study. On the other hand, the labour cost required in replenishing the loose material was not estimated in this study, hence the overall cost could be underestimated in the high replenishment strategy. However, this still shows that using materials that are easily available locally can help reduce production cost.

The TPPM cost analysis demonstrated that when managed identically, an "undocked enriched" scenario generated a higher net margin per pig than "docked barren". Thus, in fully-slatted systems, the extra cost of appropriate enrichment materials can potentially be compensated by improved growth, and as a consequence reduced feed costs and increased carcass weight of undocked pigs. However, it should be noted that the current cost estimation of "undocked enriched" did not include the initial investment in the elevated racks, wood dispensers, the chains and other fixings, as they were already installed when the study commenced. Moreover, the actual time and cost of labour involved in managing the enrichment was unable to be ascertained since the experimenter who was responsible for checking and replenishing the enrichment was often taking experimental measurements at the same time. There could also be higher potential costs of medical treatment and hospital pen requirement due to higher risk of tail biting outbreaks in undocked pigs. On the other hand, the cost estimation for "docked barren" did not include the extra labour required to conduct tail docking. The actual enrichment cost could be slightly higher considering the pigs only had one item per 12 pigs and the rate of consumption could be higher than when multiple items were available. Since the actual consumption and replacement of enrichment was not recorded for "docked barren", the estimation of enrichment cost could also be underestimated. D'Eath et al. (2016) modelled different tail docking and housing scenarios and found the net profit margin for the "standard docked" scenario (docked pigs with higher stocking density and basic enrichment) was still higher than "enhanced undocked" (undocked pigs with slightly lower stocking density and some straw provision). The main differences in their modelling were the costs for enrichment materials, labour and higher space requirement. In the current comparison, stocking density was actually higher in "undocked enriched", and therefore the cost difference could be greater. Further investigation that includes the capital investment of more permanent fittings and their depreciation, the labour cost in maintaining the enrichment or conducting tail docking, and any medical expenses incurred due to tail biting, are needed to generate a more in-depth cost analysis. Nevertheless, the €4.37 increased profit margin per pig for "undocked enriched" production scenario is still very positive in showing the potential advantage in rearing undocked pigs with sufficient enrichment provision.

6.5.5 Tail lateralisation and posture

Pigs showed lateralised tail curling positions, although no particular side bias (left or right) at the population level was found, which agrees with Goursot et al. (2018). Neither was there a treatment effect on tail lateralisation, but more pigs were recorded as ambiguous ("middle" position) when they had tail lesions; the higher the tail lesion scores were, the more likely pigs' tail lateralisation became inconsistent with their default bias. The main reason why tail lateralisation became ambiguous when higher tail lesions were recorded was because when pigs' tails were bitten, shortened or inflamed, the tail positions changed more often or were less clear. Similar results from tail posture scores confirmed this, showing a higher probability of curled-up tails when tail lesion scores were lower. Since tail lateralisation could only be scored while the tails were curled up, it is understandable why higher tail lesion scores might have resulted in more inconsistency in tail lateralisation scores as well.

In dogs, tail wagging which was biased to the left side (activation of the right hemisphere) was shown to reflect fear and aggression (Leliveld et al., 2013). In the current study, male pigs had a higher percentage of left bias, which agrees with findings in past studies that male pigs perform more aggressive behaviours than females (Chou et al., 2019, Haigh et al., 2019).

The tail lateralisation during the suckling stage was not recorded, and it would be interesting to see how early tail bias may start to develop and stabilise. Some have suggested that early life stress could contribute to a right hemispheric bias (Rogers, 2011), although our results showed no pre-weaning treatment effect on lateralisation later in life. As all piglets were reared in conventional farrowing crates, the enrichment alone might not have affected their stress levels, but further evidence is required. Tail lateralisation in pigs could be explored further, especially in improving understanding whether there are underlying mechanisms related to emotional states and other biological functions, or if there are other influences such as genetic differences. Nonetheless, tail lateralisation bias may imply that there are subtle functions of the pigs' tail, such as social communication and expression of emotional state, which may exist but are not yet explored (Rogers, 2010). This reiterates the importance of keeping tails undocked, as they are part of pigs' full functional physicality.

The results of the current study demonstrate that tail posture scans could be used as an early warning sign for the onset of tail biting outbreak as described in Lahrmann et al. (2018) and Wedin et al. (2018). Similar to what these authors found, hanging and tucked tail posture began to appear in tail biting outbreak pens around 3 days before the onset of an outbreak, and a higher proportion of down and tucked tails were recorded in outbreak pens than the control (no outbreak) pens. Thus, tail posture is indeed a useful on-farm tool for early detection of tail biting outbreaks. However, a challenge could be observing all tails from outside the pen, as this is dependent on body posture, group size, and normal tail movement (e.g. caused by exploration of the environment or the enrichment). As previously stated, tail posture can be influenced by emotions, and more tail wagging and posture changes have been seen during positive events (Reimert et al., 2013). Recently, automatic tracking was developed to constantly monitor tail posture change among large groups of pigs, and this may facilitate more correct and efficient recording of tail postures on commercial farms (D'Eath et al., 2018).

6.6 Conclusions

Providing pigs with a variety of enrichment items that are compatible with fully-slatted floors can reduce the risk of tail biting, although sporadic tail biting outbreaks still happened. The proportion of pigs which had at least part of the tail amputated and had to be removed temporarily due to tail biting was substantially decreased compared to the study in the previous chapter (**Chapter 5**), and all but one pig was reintroduced back to the original group after tail biting was under control. Early exposure to point-source enrichment items in the pre-weaning stage did not seem to exert a strong influence on pigs' later life performance or behaviours in general, compared to post-weaning enrichment provision. Although a high rate of enrichment replenishment further reduced the occurrence of damaging behaviours and improved growth rate in the finisher stage, the overall level of tail biting was similar across treatments. This study suggests that it is possible to find an economically feasible way to reduce the risk of tail biting in undocked pigs on fully-slatted floors by using an appropriate quantity and quality of point-source enrichment items.

Chapter 7 Multi-Step Tail Biting Outbreak Intervention Protocols for Pigs Housed on Slatted Floors

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This chapter had been previously presented as a poster in: **Chou, J.-Y.**, Sandercock, D. A., D’Eath, R. B. and O’Driscoll, K. 2017. Entail: Control strategies for tail-biting outbreaks among undocked pigs. Proceedings of the Teagasc Pig Development Department Research Dissemination Day, 29-31 May, Ireland.

Introduction to Chapter 7

Due to the multifactorial nature of tail biting, even on well-managed farms with straw provision, tail biting can still occur. Besides finding strategies to reduce the risk of tail biting, it is equally important to investigate methods to intervene when tail biting outbreaks happen. In Chapter 5 and 6 undocked pigs were used, and tail biting incidences were observed often; therefore, a predefined intervention protocol was used throughout the two studies to collect enough data on tail biting outbreaks and interventions that it could be analysed statistically. Thus, the data collection for this chapter was completed within the studies described in the previous two chapters (**Chapter 5 and 6**), and the data analysis and subsequent publication was the result of a Short Term Scientific Mission awarded to me by the Grouphousenet (COST-Action CA15134). I contributed to the protocol design and implementation, data collection, statistical analysis, data presentation, original draft preparation and review and editing of the final publication. Dr Irene Camerlink also contributed to part of the original draft preparation, data presentation and data analysis.

animals

Article

Multi-Step Tail Biting Outbreak Intervention Protocols for Pigs Housed on Slatted Floors

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Simple Summary: Tail biting is an unpredictable and costly damaging behaviour among pigs that causes painful injuries. A major concern of the industry is how to control tail biting outbreaks when they occur. We aimed to evaluate the effectiveness of three different interventions to overcome tail biting outbreaks: removing biter, removing victim, or providing three ropes; deployed in random order. If the first intervention failed, a second was used, and then a third if that also failed. Data were collected from two studies in which a total of 1248 pigs (96 pens) were housed on fully-slatted floors. Forty tail biting outbreaks were recorded, of which twenty were resolved using only one intervention. Eighty percent of all outbreaks were controlled within three intervention steps. Adding ropes was the fastest way to stop an outbreak but did not stop more than the other strategies; success depended more on the proportion of tail biting pigs in the pen than the intervention used. Removed victims and biters were successfully reintroduced back to the original group, following set rules. This is crucial to reduce the need for space and renders the interventions applicable on commercial farms. It is promising that most outbreaks were overcome using these cost-effective measures.

Abstract: Solutions are needed to keep pigs under commercial conditions without tail biting outbreaks (TBOs). However, as TBOs are inevitable, even in well managed farms, it is crucial to know how to manage TBOs when they occur. We evaluated the effectiveness of multi-step intervention protocols to control TBOs. Across 96 pens (1248 undocked pigs) managed on fully-slatted floors, 40 TBOs were recorded (≥3 out of 12–14 pigs with fresh tail wounds). When an outbreak was identified, either the biters or the victims were removed, or enrichment (three ropes) was added. If the intervention failed, another intervention was randomly used until all three interventions had been deployed once. Fifty percent of TBOs were controlled after one intervention, 30% after 2–3 interventions, and 20% remained uncontrolled. A high proportion of biters/victims per pen reduced intervention success more so than the type of intervention. When only one intervention was used, adding ropes was the fastest method to overcome TBOs. Removed biters and victims were successfully reintroduced within 14 days back to their home pens. In conclusion, 80% of TBOs were successfully controlled within 18.4 ± 1.7 days on average using one or multiple cost-effective intervention strategies.

Keywords: undocked tail; tail docking; tail biting; fully slatted floor; victim; enrichment; tail score; pig *animals*

MDPI

Article

Multi-Step Tail Biting Outbreak Intervention Protocols for Pigs Housed on Slatted Floors

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Simple Summary: Tail biting is an unpredictable and costly damaging behaviour among pigs that causes painful injuries. A major concern of the industry is how to control tail biting outbreaks when they occur. We aimed to evaluate the effectiveness of three different interventions to overcome tail biting outbreaks: removing biter, removing victim, or providing three ropes; deployed in random order. If the first intervention failed, a second was used, and then a third if that also failed. Data were collected from two studies in which a total of 1248 pigs (96 pens) were housed on fully-slatted floors. Forty tail biting outbreaks were recorded, of which twenty were resolved using only one intervention. Eighty percent of all outbreaks were controlled within three intervention steps. Adding ropes was the fastest way to stop an outbreak but did not stop more than the other strategies; success depended more on the proportion of tail biting pigs in the pen than the intervention used. Removed victims and biters were successfully reintroduced back to the original group, following set rules. This is crucial to reduce the need for space and renders the interventions applicable on commercial farms. It is promising that most outbreaks were overcome using these cost-effective measures.

Abstract: Solutions are needed to keep pigs under commercial conditions without tail biting outbreaks (TBOs). However, as TBOs are inevitable, even in well managed farms, it is crucial to know how to manage TBOs when they occur. We evaluated the effectiveness of multi-step intervention protocols to control TBOs. Across 96 pens (1248 undocked pigs) managed on fully-slatted floors, 40 TBOs were recorded ($\geq$3 out of 12–14 pigs with fresh tail wounds). When an outbreak was identified, either the biters or the victims were removed, or enrichment (three ropes) was added. If the intervention failed, another intervention was randomly used until all three interventions had been deployed once. Fifty percent of TBOs were controlled after one intervention, 30% after 2–3 interventions, and 20% remained uncontrolled. A high proportion of biters/victims per pen reduced intervention success more so than the type of intervention. When only one intervention was used, adding ropes was the fastest method to overcome TBOs. Removed biters and victims were successfully reintroduced within 14 days back to their home pens. In conclusion, 80% of TBOs were successfully controlled within 18.4 ± 1.7 days on average using one or multiple cost-effective intervention strategies.

Keywords: undocked tail; tail docking; tail biting; fully slatted floor; victim; enrichment; tail score; pig

1. Introduction

Tail biting in commercially reared pigs is an injurious behaviour that is one of the main animal welfare issues in the pig sector. Despite routine tail docking being banned in the EU [1], more than 95% of pigs are tail-docked shortly after birth to reduce tail biting using an exemption from the regulation [2]. The exemption is allowed when farmers demonstrate that tail biting on their farm cannot be properly controlled by other means than tail docking [3]. However, with increasing pressure from the public and governments to stop tail docking [4], an expanding body of research has focused on finding solutions to reduce, predict, and prevent the occurrence of tail biting amongst undocked pigs [5–8].

Due to the multifactorial nature of tail biting behaviour, it will likely prove impossible to completely eradicate it; even in outdoor pig herds, there have been records of tail biting, albeit with a much lower risk [9]. Severely injurious tail biting behaviour can quickly spread from a single pig to its pen mates and even to other pigs in adjacent pens [10]. This kind of rapid development and contagion is defined as a tail biting outbreak [11] and is associated with considerable economic losses [3]. It is, therefore, crucial to investigate intervention strategies to control tail biting outbreaks when they occur to reduce the negative consequences for farm economics and animal welfare.

To date, most of the advice that farmers receive regarding different tail biting outbreak interventions is based on experience and anecdotes, and there are few scientific studies that specifically evaluate intervention effectiveness. This is primarily because tail biting outbreaks are unpredictable in nature, which creates difficulty in terms of data collection [5]. There have been attempts to stimulate tail biting outbreaks for research purposes, but these often fail to induce the behaviour [12]. Bracke used a rope model as surrogate to tail biting and showed that, when ropes were covered with either Stockholm tar or Dippel's oil, pigs' rope manipulation reduced. Therefore, these two substances may be used to halt tail biting [13]. However, pigs' reaction to a synthetic rope and an actual pig's tail is likely to be different, especially in the context of a tail biting outbreak. Moreover, for ethical reasons, tail biting occurrences in research settings are treated early on to minimize harm inflicted on experimental animals. For instance, in a pioneering study of tail biting outbreak management, an outbreak was defined as occurring when one pig had a fresh tail wound and one other pig had a tail wound/bite mark out of a pen of 10 pigs [14]. Later, Lahrmann et al. classified tail biting outbreaks using detailed examination of the tail for lesions to study early intervention strategies [15]. In their study, when four out of 30 pigs/pen had tail lesions, regardless of severity, these pens were classified as outbreak pens [15]. The assessment of how effective the interventions would be was dependent on the definitions given—whether at an earlier or a later stage of development. Another study classified outbreaks in a more detailed fashion into two categories; an *underlying* outbreak was detected by detailed tail examination, and a *severe* outbreak was detected when blood and severe damage could be seen on two out of 30 pigs (without close-up examination) [16]. The severe outbreaks were the ones that included clinical signs, but the damage observed by the authors was still quite varied [16]. In practice, it is unlikely that farmers will enter the pens to assess tail damage in individual pigs. Entering the pen is also not recommended from the perspective of disease transmission. Thus, recent studies on early detection of tail biting have begun to adopt a more commercially relevant definition of an outbreak based on pen-side recordings to improve the transferability of results to commercial practice [17,18].

Surveys have shown that farmers from different countries in Europe have different attitudes on how to handle tail biting outbreaks. Dutch pig farmers prefer to remove both tail biters and victims [19]. Swedish farmers intervene by removing biters, followed by victims, then increasing straw rations [20]. Farmers in Finland reported using a variety of intervention methods including removing biters, adding more bedding materials, removing victims, and reducing stocking density [21]. However, in England and Ireland, surveys have shown that farmers mainly tend to remove the victims as the primary solution [22,23]. In many instances, removing animals from the group was considered an important step to control tail biting, but continuous removal of animals can create issues due to limited availability of hospital pens on farms [5,21]. The removed pigs are rarely reintroduced to avoid aggression [24] and hence create an additional space requirement with extra cost and management.

Zonderland et al. (2008) had to regroup the removed biters into new pens constantly to limit space use but made no mention of the regrouping methods and measures to reduce aggression at mixing [14]. Based on current research recommendations, provision of loose straw can stop a tail biting outbreak effectively and efficiently [14,15], even with only 10 g of long straw per pig twice a day. In housing with partly or fully slatted floors, however, the provision of straw can block the slurry system [5], even when only as little as 5 g/pig/day of straw is provided [14]. There is, therefore, a need for investigation of practical measures to tackle tail biting outbreaks that are compatible with slatted floor systems, which still predominate in pig production.

We aimed to evaluate the effectiveness of different intervention methods incorporated in a multi-step protocol to control tail biting outbreaks in pigs under commercial housing conditions. Tail biting outbreak data were collected from pigs housed on fully-slatted floors. Outbreaks were recorded according to a clear definition and a threshold using a level of tail damage that could easily be seen from outside the pen, which we believe is similar to that used in commercial practice. Three different intervention methods suitable for use in practice were randomly assigned to pens with an outbreak: removing the biters, removing the victims, or adding additional enrichment in addition to material already present. The intervention was classified as successful only when the removed biters and/or victims could be reintroduced into the original group without further tail biting. This study thereby addresses two aims: to compare practical intervention strategies during tail biting outbreaks and to evaluate the possibility of reintroduction of removed pigs back to the group.

2. Materials and Methods

Data were collected from two similar research trials conducted at the Teagasc Pig Research Facility, Moorepark, Ireland, both investigating tail biting in undocked pigs. The first trial studied the effect of dietary fibre and a single environmental enrichment (for details, see Chou et al. (2019) [25]), and the second looked at the effect of different enrichment management strategies (for details, see Chou et al. (2019) [26]). Both trials were conducted at the same research facility using the same pig herd and managed with identical husbandry practices (housing, ventilation, and lighting). However, the major difference between two trials was the complexity of environmental enrichment used. Pigs in the second trial were housed in a more enriched environment (eight different point-source enrichment items including an elevated rack with grass per 12 pigs) compared to the first trial (one point-source item per 14 pigs). Specific steps in data analyses were taken to account for this variation.

The trials were approved by the Teagasc Animal Ethics Committee (TAEC124/2016 and TAEC163-2017).

2.1. Animals and Housing

Across 96 groups (48 groups in each trial), 1248 male and female pigs (Large White × Landrace) were studied from weaning to slaughter (from 5 to 20 weeks of age). Pigs were reared according to conventional commercial practice in Ireland where male piglets are not castrated. Pigs' tails were left intact (not docked), but their needle teeth tips were clipped at 1 day of age to reduce skin lesions and damage to sows' udders. Groups consisted of 12 to 14 pigs and were of mixed sex (50/50 male/female ratio). The weaner pens measured 2.4 × 2.6 m and fattener pens 4 × 2.4 m, and both had fully slatted floors. In the weaning housing, the temperature was kept at around 28 °C immediately post-weaning and reduced by 2 °C every 2 weeks thereafter, while in the fattening housing, the temperature was maintained at 20 °C. Lighting in the weaner house was provided by artificial lighting at 150 lux and at 130 Lux in the finisher house, from 8:00 to 18:00, with windows along the walls providing natural daylight. The pigs had ad libitum access to water via a nipple drinker and dry pelleted feed from a single space wet-dry feeder (standard weaner feed: metabolisable energy 13.7 MJ/kg, crude protein 196 g/kg, crude fibre 37 g/kg; standard finisher feed: metabolisable energy 12.5 MJ/kg, crude protein 142 g/kg, crude fibre 59 g/kg). At 11 weeks of age, the pigs were transferred to the finisher housing without further regrouping. Spare empty pens of the same dimensions, which were in the same room or building and under the same management as the experimental pens, were used as the hospital pens. The hospital pens had point-source items available as enrichment.

2.2. Recording of Tail Injuries and Tail Scores

Pigs were individually identified by ear tags. Routine health checks were made by the experimenters three times daily (9:00, 14:00, and 17:00, when the pigs were most active) and by the farm staff at different time points throughout the day (9:00–12:00 and 14:00–16:00). All inspections were conducted from outside the pen. At each of these health checks, pigs' tail were inspected using a visual guide to look for swollen tail wounds and fresh dripping blood (maximum damage/blood on the scoring system developed by the FareWellDock consortium [27], Appendix A Figure A1). Pigs observed to be actively tail biting were also identified and recorded as a "biter" using their ear tag number. As per the experimental protocols of the main studies, more detailed tail lesion scoring on every individual pig was conducted every two weeks. This was carried out within the pen by a single recorder using the same scoring system.

2.3. Definition of a Tail Biting Outbreak

A tail biting outbreak within a pen was defined as (a) 3 or more pigs in a pen (of 12–14 pigs, i.e., 21.4–25%) with fresh dripping blood (blood score 3 of the FareWellDock system) present on their tails, clearly visible from outside the pen, (b) 1–2 pigs (not necessarily the same pigs) with fresh bloody tails in a pen, but for 72 h, or (c) 3 or more pigs with tail damage score 3 (of the FareWellDock system) for 72 h, but fresh blood not present. Instances of (a) were further classified as acute outbreaks, whereas (b) and (c), i.e., lasting ≥ 72 h, were considered slow outbreaks.

2.4. Intervention Methods

Three intervention methods were used:

1. Removing victims: Victims, identified through the methods described above, were removed and treated with topical antibiotic spray (Alamycin® Aerosol, Norbrook, Newry, Northern Ireland) on the tail and rear area to prevent infection of affected tails. Dettol spray (Dettol, Reckitt Benckiser, Slough, UK, diluted at 1:20 ratio) was also used to reduce the scent and the attention towards Alamycin®. Removed pigs were housed by original pen in separate hospital pens and therefore not mixed with others.

2. Removing biter(s): Once an outbreak occurred, biters were identified through 10–15 min of behaviour observation, examination of tails (tail-biters often do not have as much tail damage as pigs that are bitten), and previous tail biting history. When only one biter was identified, it was removed with another non-bitten pig (having uninjured full-length tails, or if there were none, a litter-mate with the lowest tail injury score) to reduce stress while away from the home pen and facilitate later reintroduction. Removed pigs were not mixed with pigs from other pens or with removed victims (as the intervention methods were not applied simultaneously for a pen). On removal of the biter(s) and any companion pig, all the victim pigs remaining in the pen were treated with Alamycin® spray (Alamycin® Aerosol) on the tail and rear area to prevent infection of affected tails. A topical spray without antibiotic (Repiderma, Intracare, The Netherlands) was applied to non-victims, and Dettol spray was also used to divert pigs' attention from the victim.

3. Adding 3 ropes: Three 1 m synthetic hemp ropes (without knots) were provided by hanging them from three different sides of the pen. An ointment (Cheno Unction, PharVet, Ireland) was applied on all tails and Dettol spray on the tail and rear area to prevent infection and reduce the scent of blood. The ointment was reapplied whenever necessary.

2.5. Intervention Protocol

This study employed a multi-step intervention protocol using the three intervention methods described above (Figure 1). The order of the three intervention methods was assigned randomly for each outbreak pen without repetition within an outbreak. When a tail biting outbreak was identified, the first intervention out of the predetermined and randomised set of protocols was applied. From the next routine inspection onwards, if fresh blood was observed on the same victim(s) or new victim(s) within 72 h after intervention, the method was regarded as having failed, and a second randomly selected intervention was deployed. An intervention was considered successful when no fresh blood was observed within 72 h.

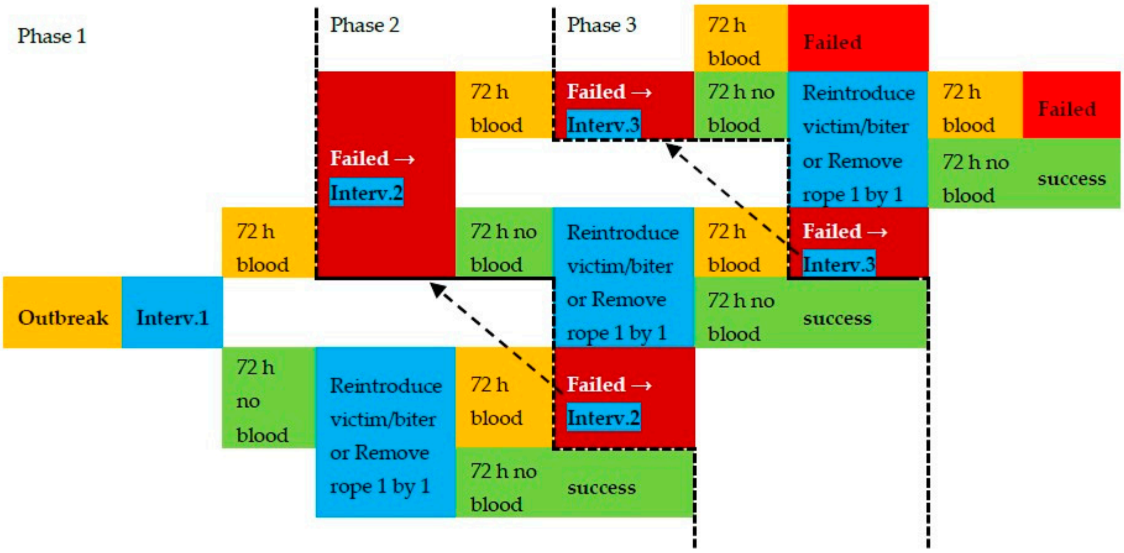


Figure 1. Protocol for the intervention (Interv.) steps after an outbreak and the classification of success and failure in Phase 1–3 (separated by dotted line). Colours indicate the action taken (blue) and the urgency of the outbreak (green = getting better/resolved and yellow/red = getting worse/could not be controlled).

Up to a maximum of 3 interventions were deployed per pen. If all intervention methods failed and tail biting still could not be controlled, other additional measures were taken (e.g., provision of more enrichment such as feed bags, quarantine of more pigs, application of ointment on tails, etc.). If the intervention was successful, the removed pigs (biters or victims) were reintroduced after the 72 h period. Upon reintroduction, three ropes were provided, and diluted antiseptic spray (Dettol, diluted at 1:20 ratio) was applied in the pen to minimise aggression, as this was a standard practice on farm. In the next 72 h, one rope was removed per day if no further biting occurred. After all ropes were removed, if no fresh blood was observed in another 72 h, the reintroduction procedure was complete, and the outbreak was deemed resolved (Table 1).

Table 1. Schematic process of a successful one-step intervention.

Day	D0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
Outbreak identified	Remove biters/+victims	Monitor	Monitor	Reintroduce + 3 ropes	Remove 1st rope	Remove 2nd rope	Remove 3rd rope	Monitor	Monitor	Monitor	Success
	Add ropes × 3			Remove 1st rope	Remove 2nd rope	Remove 3rd rope	Monitor	Monitor	Monitor	Success	

If the intervention was "adding rope", then after the intervention was successful, one rope was removed per 24 h until all three ropes were removed from the pen (within 72 h). Similarly, as previously described, if no fresh blood was observed in the next 72 h, the outbreak was deemed resolved (Table 1).

Removed pigs were never mixed with pigs unfamiliar to them. In order to facilitate reintroduction of the removed animals, besides using ropes and antiseptic spray as distractions as described above, the following rules were applied: (a) at least two pigs were removed together and later reintroduced together, (b) pigs were always reintroduced to the group where they came from, and (c) pigs were returned within 14 days of removal, which is a cut-off point decided in advance to minimise possible aggression. Within 72 h after each outbreak took place, any recurring outbreak was regarded as the same outbreak, and that intervention method was considered as having failed. Therefore, the next intervention was deployed instead of being treated as a new outbreak.

In trial 1, the choice of the intervention was fully randomised without replacement. Because this led to an overrepresented group in which the biter was removed as the first intervention (50%; 13 out of 26 first interventions), in trial 2, the interventions were randomised, but the first intervention method was controlled to best balance the frequency of all three methods to 1/3. The implemented protocols were clearly recorded and signposted on treatment pens so that no other procedures were taken to confound the effects.

2.6. Ethical Considerations

If, at any stage, tail damage was severe (e.g., suspected amputation of part of the tail or severe bites and inflammation), an injection of antibiotic (Norocillin®, Norbrook, Newry, Northern Ireland) and analgesic (Loxicom®, Norbrook, Newry, Northern Ireland) was administered to the affected pig. If, after an intervention, bitten pigs had scabs or tail wounds that were a risk of infection, then reintroduction or removal of ropes was postponed for ethical reasons. In pens without reaching the criteria of a tail biting outbreak, removal of tail bitten victims was carried out using the same protocol as for outbreaks (removal with a companion and reintroduction) whenever appropriate, and medical treatment was applied to the tails as part of the main studies' procedures. If pigs had prolonged tail infection without recovery or if the tail injury affected their overall health and welfare, as evaluated by the experimenter and the staff, then they were removed from the study, and euthanasia was practiced as a humane end point when necessary.

2.7. Data Analyses

Data were analysed in SAS version 9.4 with each outbreak occurrence as the statistical unit. If the same pen had more than one outbreak, only the data of the first outbreak per pen were analysed together. As there were only six out of 34 pens that had a second outbreak, these data were described by descriptive statistics.

Differences between the trials were compared using the Chi-square goodness of fit test for the number of pens with outbreaks, the number of pens with slow outbreaks, and the number of successful interventions. A 2-sample t-test was used to compare the mean duration of outbreaks, and the Mann–Whitney test was used for number of interventions used (not normally distributed). The course of the outbreaks per intervention protocol was analysed using Kaplan–Meier survival analysis with the Lifetest procedure. The pair-wise comparisons between the protocols were done by paired testing using log-rank test.

To assess the effect of intervention method on the control of tail biting outbreaks, the duration of the outbreaks and the proportion of pigs with tail score 0, 2–3, or 3 were analysed using general linear mixed models (mixed procedure), whereas the intervention success was analysed using a logistic model (GLIMMIX) using the binary distribution and the logit link function. In both models, batch (i.e., replicate) nested within trial was included as random effect.

In both models, the initial explanatory variables were trial (1, 2), month of the year (12 months), first or last method applied (biter(s) removed (B), victim(s) removed (V), ropes given (R)), number of interventions used (1, 2, 3), interaction between the last method × number of interventions, proportion of biters and victims identified during the course of the outbreak, week of age at time of outbreak, and outbreak type (acute/slow). Variables were included in the model if their p-value as a single variable in the model was <0.10 and their inclusion improved the goodness of fit of the model. Models were assessed for the distribution of the residuals. The final model for duration included the number of interventions, the proportion of biters, the proportion of victims, and the interaction "last method

× number of interventions". The final model for intervention success included the first and the last method, age, the proportion of biters, and the proportion of victims.

The success of adding rope as an intervention was further analysed independently between trials using the same method as described above to assess if different enrichment backgrounds (i.e., the routine enrichment pigs were provided with on an ongoing basis during their lives) influenced the effectiveness of intervention by adding additional ropes.

Paired *t*-tests were used to compare the proportion of pigs with different lesion scores before and after the outbreak for normally distributed variables (proportion of pigs with moderate tail damage and blood score 2 & 3), and the Mann–Whitney test was used to compare non-normally distributed variables (proportion of pigs with tail damage or blood recorded at "score 0" and "score 3").

Data are presented as least square means with standard errors unless otherwise indicated.

3. Results

Over two trials, a total of 40 outbreaks were recorded in 34 pens. Although there were significantly more pens with tail biting outbreaks and longer outbreaks in trial 1 compared to trial 2 ($p = 0.03$, Table 2), the pattern of occurrence of tail biting outbreaks over time was similar between the trials (Figure 2). Figure 2 also shows that outbreaks started to occur about 11 days, and peaked around three weeks, after weaning. On average, there were 2.8 ± 0.3 biters and 7.7 ± 0.4 victims per pen of 12–14 pigs. The average proportion of biters (out of the total number of pigs in the pen) identified over the course of an outbreak per pen was 0.21 ± 0.02, and the proportion of victims was 0.58 ± 0.03. An average of 3.1 ± 1.7 biters was removed for "remove biters" interventions, and 4.9 ± 2.4 victims were removed for "remove victims" interventions. In total, five pigs were removed from the main study of trial 1, and four pigs (three in trial 1 and one in trial 2) were euthanised due to tail biting outbreak. Across the trials, six pens had a second recurring outbreak (Table 2) after the first had been resolved, and eight outbreaks were slow (Table 2), meaning that the outbreak lasted >72 h.

Table 2. Differences in tail biting outbreaks between the two trials.

Comparisons	Trial 1	Trial 2	Test	*p*-Value
Pens with outbreaks	22	12	X^2 (1, N = 96) = 4.55	0.03
Pens with recurring outbreaks	4 (18.2%)	2 (16.7%)	-	-
Pens with slow outbreaks (>72 h)	5 (19.2%)	3 (21.4%)	X^2 (1, N = 40) = 0.03	0.87
Mean duration of outbreaks (d)	19.6	13.3	t (34) = 2.28	0.03
Successful interventions (%)	76.92	85.71	X^2 (1, N = 40) = 0.44	0.51
Interventions used (median)	2	1	U (N_1 = 26, N_2 = 14) = 267	0.58

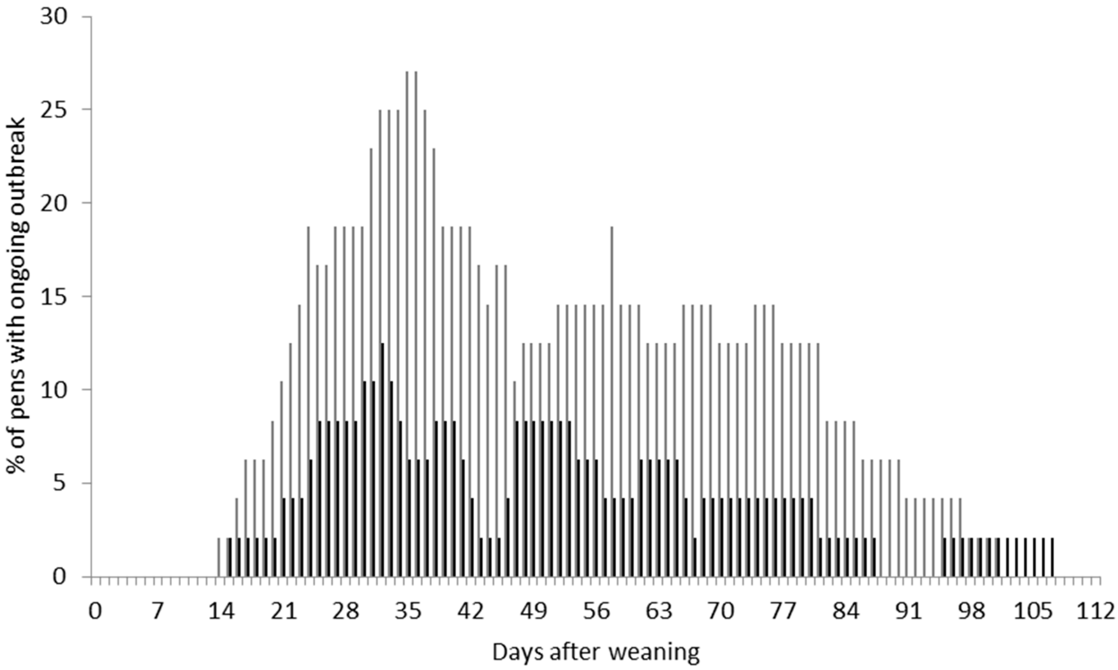


Figure 2. Percentage of pens with ongoing tail biting outbreaks (defined as being between the criteria for the start of an outbreak and successful resolution, criteria for each of these are explained in the text) plotted against days post-weaning within trial 1 (light grey) and trial 2 (black).

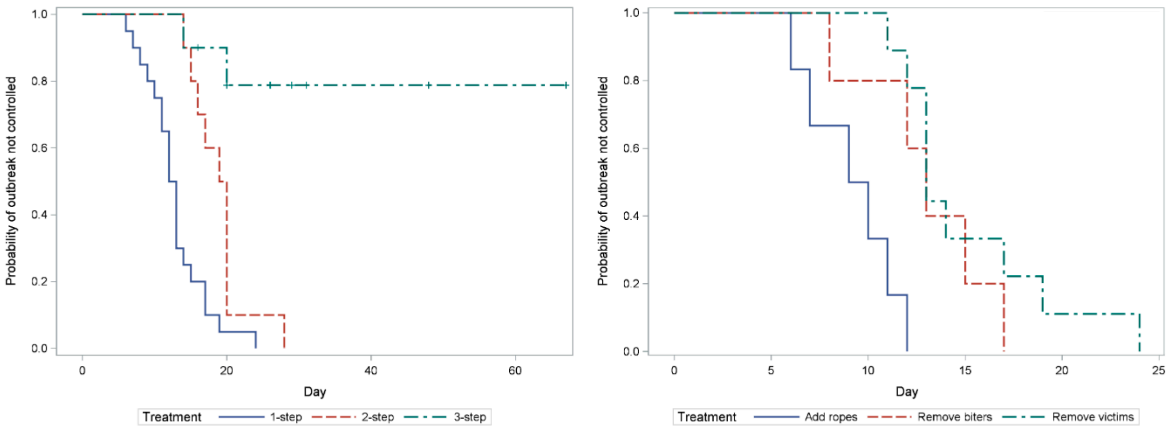
3.1. Intervention Success

All three interventions were equally represented across the intervention steps (maximum three steps; Table 3).

Table 3. The number of successes and failures for each of three intervention methods (remove biter: B; remove victim: V; give ropes: R) over 3 steps (percentages shown in brackets).

Method	1st Step	Result	Count (Percentage)	2nd Step	Result	Count (Percentage)	3rd Step	Result	Count (Percentage)
B	14 (35.0%)	Fail Success	9 (22.5%) 5 (12.5%)	7	Fail Success	3 (15.0%) 4 (20.0%)	2	Fail Success	1 (10.0%) 1 (10.0%)
V	16 (40.0%)	Fail Success	7 (17.5%) 9 (22.5%)	8	Fail Success	5 (25.0%) 3 (15.0%)	2	Fail Success	1 (10.0%) 1 (10.0%)
R	10 (25.0%)	Fail Success	4 (10.0%) 6 (15.0%)	5	Fail Success	2 (10.0%) 3 (15.0%)	6	Fail Success	6 (60.0%) 0 (0.0%)
Total	40	Fail Success	20 (50.0%) 20 (50.0%)	20	Fail Success	10 (50.0%) 10 (50.0%)	10	Fail Success	8 (80.0%) 2 (20.0%)

Exactly half of the interventions (20/40) were successful after the first intervention was carried out. Ten outbreaks required a second intervention, and another ten outbreaks required a third intervention. Of these last ten, only two interventions were successful (i.e., eight out of 40 outbreaks were not successfully resolved after all three intervention strategies were applied). Survival analysis showed that if three interventions were used, there was an 80% predicted chance of the tail biting outbreak continuing (Figure 3a).



(**a**) (**b**)

Figure 3. Kaplan–Meier survival plots for the probability (y-axis) of a tail biting outbreak continuing, where higher survival probability represented a higher chance that the tail biting outbreak was continuing and not controlled. (**a**) Number of interventions used, blue solid line: outbreaks with one intervention used, red dashed line: two interventions, and green dashed-dotted line: three interventions. (**b**) The outbreaks that were successfully controlled with one intervention: blue solid line: adding ropes, red dashed line: removing biters, green dashed-dotted line: removing victims.

The success of the last method applied tended to be the lowest in the rope treatment ($F_{2,25} = 2.55$; $p = 0.09$), with the probability of success for removing the biter being 0.90 ± 0.10, for providing ropes 0.54 ± 0.14, and for removing the victim 0.91 ± 0.09. Success of the last used intervention was related to the proportion of biters per pen, with more biters increasing the chance of failure (b = 20.77 ± 8.35/0.1 increase in proportion of biters; $F_{1,25} = 6.18$; $p = 0.02$; Figure 4). Similarly, the failure was related to the proportion of victims in the pen (b = 10.10 ± 4.60/0.1 increase in proportion of victims; $F_{1,25} = 4.82$; $p = 0.04$; Figure 4). Specifically, Figure 4 shows that the likelihood to successfully overcome an outbreak is lower when more biters are in the pen as compared to having the same number of victims. The probability of success of the last method was greater when pigs were older (b = −0.626 ± 0.325/week of age; $F_{1,26} = 3.71$; $p = 0.065$). Trial, month of the year, and whether outbreaks were acute or slow were not significantly related to the success of the last method ($p > 0.10$). The success of the first intervention was not influenced by the three methods used either ($p > 0.10$).

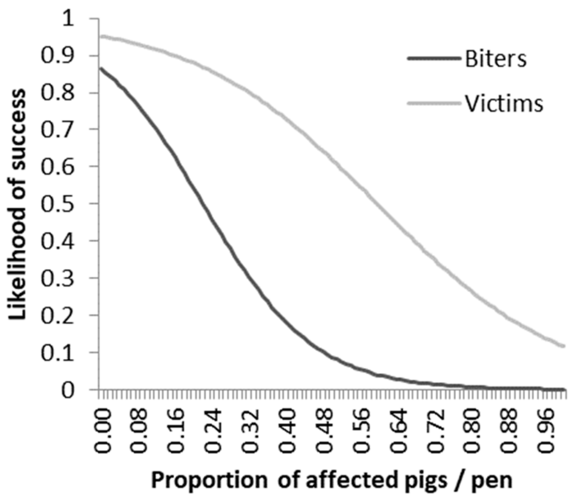


Figure 4. Probability of a successful intervention based on the proportion of biters and victims identified during the course of an outbreak in the pen. The curves are plotted using the intercepts and betas extracted from the logarithmic model of the data.

3.2. Intervention Duration

The duration of an outbreak increased with the number of interventions needed to terminate it (b = 6.89 ± 2.786/intervention; $F_{1,22} = 6.25$; $p < 0.001$). When only one intervention was used, providing ropes resulted in a shorter outbreak duration than removing the victim (add ropes 9.17 ± 1.50 d v's remove victims 15.78 ± 1.23 d, $p = 0.01$; Figure 3b) and tended to be shorter in duration compared to the strategy of removing the biter based on Kaplan–Meier survival analysis (remove biters 13.00 ± 1.65 d, $X^2 = 4.77$, $p = 0.05$; Figure 3b). There was no difference in the duration of the outbreak between removing the biter versus removing the victim ($p = 0.40$). When there were two intervention strategies needed to overcome the outbreak, there was no difference in the duration of the outbreak based on the last strategies applied ($p = 0.11$). As single variables in the model, the proportion of biters and victims and the interaction between number of methods and the last method significantly influenced the duration, but these effects became non-significant when they were combined into the model with number of interventions ($p > 0.10$). Outbreak duration did not significantly differ between trials, months of the year, what the last method was, the age of the pigs, or whether the outbreak was acute or slow ($p > 0.10$).

3.3. Tail Lesion Scores

Detailed tail lesion scores were obtained as per the main studies' protocols at a fortnightly basis. As a result, tail lesions were scored on average 6.9 ± 0.8 days before outbreaks began and 8.6 ± 1.0 days after outbreaks finished. The proportion of pigs with moderate or severe tail scores (score 2 and 3 combined) and severe tail scores (score 3) was lower when the outbreak was resolved compared to before the onset of the outbreak, both in terms of tail damage and blood presence (Table 4). Pigs with no tail damage (score 0) did not differ before or after the outbreak, but more pigs did not have blood on tails after the outbreak (Table 4).

Table 4. Proportion of pigs (mean ± s.e.) with different levels of tail damage and blood presence scores recorded before the onset of outbreaks and after outbreaks were resolved.

Tail Damage	Before [1]	After [2]	Test	*p*-Value
Score 0	0.11 ± 0.02	0.15 ± 0.03	$U = 1115.0$	0.481
Score 2 & 3	0.26 ± 0.03	0.10 ± 0.02	$t = 4.00$	< 0.001
Score 3	0.09 ± 0.02	0.02 ± 0.01	$U = 1397.0$	0.006
Blood Presence	**Before [1]**	**After [2]**	**Test**	***p*-Value**
Score 0	0.21 ± 0.03	0.35 ± 0.04	$t = -2.77$	0.007
Score 2 & 3	0.38 ± 0.04	0.16 ± 0.03	$t = 4.67$	< 0.001
Score 3	0.08 ± 0.02	0.03 ± 0.01	$U = 1334.5$	0.048

[1] Score recorded on average 6.9 ± 0.8 days before outbreaks began. [2] Score recorded on average 8.6 ± 1.0 days after outbreaks finished.

The proportion of pigs with a severe tail damage score (score 3) after outbreaks was affected by the proportion of victims in the pen only when included as a single variable in the model (b = 0.07 ± 0.03/0.1 increase in proportion of victims $p = 0.04$). There was no difference in the proportion of pigs with moderate damage or blood score (score 2 and 3 jointly), severe blood score (score 3), or no lesion (score 0) between numbers of intervention used, last methods, types of outbreak, proportion of biters present, and duration of outbreak.

4. Discussion

This study aimed to explore the outcome of three tail biting intervention methods in a multi-step protocol during tail biting outbreaks that were defined to reflect what happens on commercial farms, both in terms of the timing and the nature of the interventions. Half of the outbreaks were controlled with only one intervention, but 20% of the outbreaks could not be overcome, even when all three intervention methods were used. The proportion of biters and victims in the pen had a greater influence on the success rate of resolving a tail biting outbreak than the intervention methods used. The multi-step intervention used in the current study required all removed pigs to be reintroduced in the home pens before an outbreak was deemed resolved, and this could be more applicable to practice where there is limited amount of extra space.

4.1. Intervention Success and Duration

By using a multi-step intervention protocol, which employs different methods progressively to accommodate situations where one intervention method fails, it was possible to increase success from 50% after one intervention to 80% of the 40 outbreaks recorded. This was a positive outcome considering that our definition of a tail biting outbreak adopted a higher threshold of injury to the pigs than was the norm in previous research (three out of 12–14 pigs with severe tail damage) [14,15]. Under commercial settings, a multi-step protocol is realistic and necessary, since farmers need to resort to all possible measures to stop the outbreak from continuing.

There was no difference between intervention methods in terms of stopping the outbreak, which agrees with a previous study that compared removing biters and adding straw as intervention methods [14]. However, outbreaks were of shorter duration when ropes were added in comparison to removing animals. This was partly due to the time required for removed tail bitten victims to recover to a state that they could be reintroduced and the time required for reintroduction of the earlier removed pigs, which was not a component of the "additional ropes" treatment. Another disadvantage of removing biters and victims was the difficulty in identifying biters, given that biters could also be victims and hence have a double "role" [28,29]. It requires time and experience to identify the pig's role through behavioural observations, which may not always be feasible on farms due to time restrictions. Moreover, a larger group size than what we had in this work (12–14 pigs) will make it more difficult to identify biters, especially if stocking density is high. This contributes to why some farmers are used to removing victims rather than biters [22,23]. Nevertheless, this study has shown that there was no difference in removing the victims or the biters, either in terms of intervention success rate or duration of the outbreak, and thus it may not have major practical implications whether the biter or the victim is removed. In this study with 48 groups of pigs, at maximum, ten hospital pens were needed to accommodate the removed pigs due to outbreaks without mixing different pens. In practice, pens could be divided into smaller pens to avoid the need for regrouping and to enable this intervention. Further work is still needed to investigate how group size may also influence the outcome of different intervention methods.

Adding in ropes reduced the outbreak duration, albeit there was no clear benefit with regard to the number of successful interventions. As previous studies suggested, ropes may not be the most effective enrichment material to stop a tail biting outbreak compared to chopped wheat straw [15]. On fully slatted floors, providing straw on the floor is not possible, and instead it could be more effective to supply loose substrates in suitable dispensers (e.g., hay racks) if placed in the correct location in the pen to avoid aggression [30].

The chance of resolving a tail biting outbreak was affected by the proportion of biters and victims identified in a pen. When more biters or victims were identified, the probability of having a successful intervention dropped. Tail biting outbreaks happen in a rapid and sudden fashion and can also spread from pig to pig [10]. The longer tail biting continues without intervention, the more pigs may become potential biters and victims. This also reiterates the importance of early detection for prompt intervention [15,17,18,31–33].

4.2. Intervention and Tail Lesion Scores

The tail lesion scores after outbreaks were resolved were lower than before, which confirmed the effectiveness of the interventions in overcoming the outbreaks. However, no difference of the tail scores was found between the three different intervention methods, the numbers of intervention used, or the duration of the outbreaks. Tail lesion scores were not scored on a daily basis or according to the onset of the outbreaks but every two weeks based on the schedule of the main studies. It is acknowledged that some tail lesions may have healed in the time between the outbreak and the recording day. The scores thus may not truly reflect the direct damage pattern within the outbreak. Previously, it was reported that the cutaneous healing of tail injuries appears to take place over 3–7 days [34], and therefore with more frequent tail lesion scoring (e.g., every 2–3 days), we may have detected differences between the intervention strategies.

4.3. Reintroduction of Ex-Biters and Ex-Victims

By using a strict protocol in removing and reintroducing pigs, the majority of pigs removed due to intervening tail biting outbreaks were able to be reintroduced. To the best of our knowledge, this study is the first to report that routine reintroductions of previously removed pigs back to the home pens is feasible after tail biting outbreaks. Although no detailed recording of skin lesions was conducted, which is the common method to score aggression between pigs [35], no overt aggression or clearly visible skin lesions were observed during subsequent routine monitoring. Nevertheless, it cannot be ruled out that some level of aggression might have occurred without clear signs. In experimental settings as well as in practice, pigs that are taken out of the pen are hardly ever reintroduced or re-mixed due to the fear of aggression at regrouping [24]. Zonderland et al. (2008) removed biter pigs from their home pen and later regrouped them into new pens instead of reintroducing them into their original group [14]. Although this regrouping did not result in further tail biting, the consequences of mixing unfamiliar animals and precautionary measures taken to reduce subsequent aggression was not reported [14]. Moreover, newly formed groups needed to occupy additional space permanently. Caution is needed when remixing or re-introducing pigs, since aggression and the negative consequences of fighting due to remixing are well-documented [24], and pigs may even start fighting upon the introduction of a previous member [36]. Successful reintroduction (i.e., with limited aggression) of a previous group member may depend on previous hierarchy, with dominant animals successfully returning after 25 days of absence, whereas subordinate animals may be attacked even after being removed for three days [36]. However, there are techniques that can help mitigate aggression at mixing [37]. Our study therefore suggests that, with good management practices and accurate record keeping, it is possible to reintroduce pigs back into their home groups, which in turn can free up space in the hospital pens and reduce the requirement for extra space.

4.4. Different Types of Outbreaks

In the current study, both the success and the duration of the interventions were affected by the proportion of biters and victims present in the pen, which might have represented different "types" of outbreaks. Depending on the clinical signs and the development phase, tail biting has been categorised in a range of different types (e.g., two-stage, sudden forceful, obsessive, epidemic [8,29]). As the occurrence of tail biting may have different origins [5,6,8,29], intervention methods could be tailored to the type of outbreak in order to stop the outbreak efficiently. For example, in the case of an obsessive biter, it might be most effective to immediately remove the biter if it can be identified. To investigate this, more outbreak data are needed than we had available. It may be necessary to use meta-analysis, which would only be possible if classification of outbreak type were standardised across experiments. Thus, it would be meaningful to construct a classification tool to help both researchers and producers identify different types of outbreaks, with the aim of determining the most effective intervention.

4.5. Limitation in Data Collection

The outbreak data used in the current study were collected from two different trials that took place in the same research facility with the same breed of pigs and management practices. Although the two trials were conducted under very similar conditions, the difference in enrichment provision could make the pigs react differently to the ropes as additional enrichment. We recognise this may influence the outcome of the outbreak interventions; therefore, in order to ensure the differences between trials were accounted for, "trial" was always included in the statistical models. There was no difference in the success of intervening with ropes between the two trials. Indeed, it can be argued that using data from two different trials does increase the validity of the protocols and their applicability under a range condition.

Furthermore, this study used a multi-step intervention protocol, which is beneficial for practical application, but this methodology also complicated the experimental design since it is impossible to predict in advance how many steps will be required before an outbreak is successfully controlled. The analysis of the intervention combinations would have benefitted from a larger number of outbreaks; however, over two trials, only 34 pens (out of 96, 35%) recorded a tail biting outbreak. Therefore, we were only able to best analyse the data by comparing the method that led to the success of the intervention (i.e., the last one). The limited number of outbreaks thus prevented a full interpretation of how different combinations and order of the methods used could have affected the success of the intervention when more than one intervention was used. Future studies with a larger scale commercial trial could explore this further.

5. Conclusions

This study developed a multi-step intervention protocol to controlling tail biting outbreaks in pigs involving the removal of either (a) the biters or (b) the victims and (c) the provision of three ropes, which has practical application in pig production systems. Eighty percent of all tail biting outbreaks were controlled within three intervention steps outlined in the protocol. Compared within one-step interventions, adding ropes resulted in relatively shorter duration of outbreaks, but there was no difference in the success rate as a last treatment between the intervention methods used. The proportion of biters and victims in a pen had the greatest influence on the success of controlling an outbreak, rather than the intervention methods used. This emphasizes the need to act promptly at, or even before, the onset of an outbreak in order to increase the likelihood of successful control. It was possible to reintroduce all removed pigs back into their home groups, which is crucial to reduce extra space requirement. As removal of pigs without reintroduction implies that the underlying problem is still prevailing, reintroduction should be considered part of a successful intervention strategy.

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Appendix A

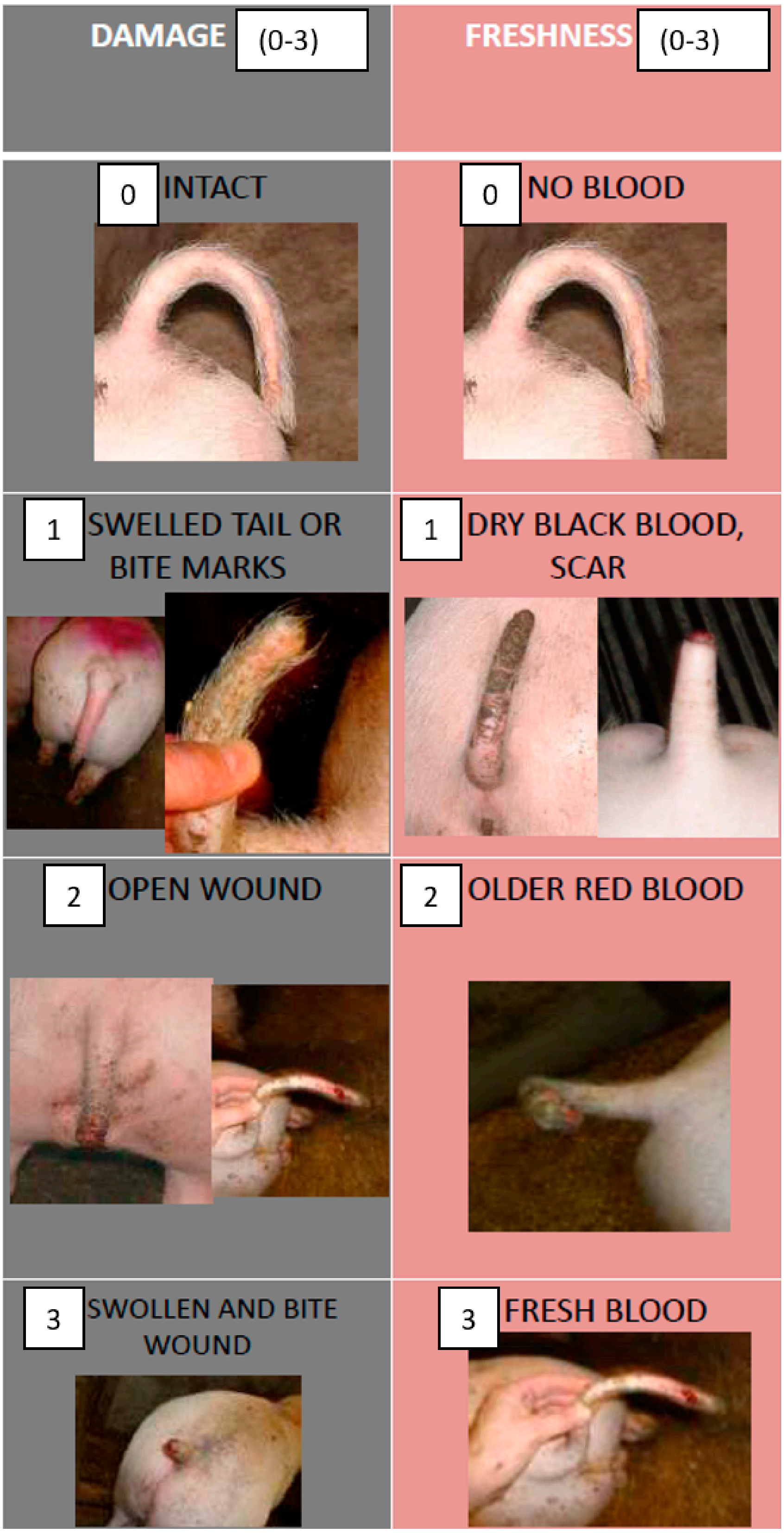

Figure A1. Tail Lesion Scoring System Developed by the FareWellDock Consortium.

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Discussion of Chapter 7

This chapter addressed the final objective of the thesis, which was to design and test an intervention protocol to stop tail biting outbreaks. An outbreak criterion at the point when tail biting had already progressed to a severe stage, with clear clinical signs of blood, and which affected a large proportion of pigs in a group (rather than one pig) was chosen, to correspond with the practical approach of this PhD thesis. Farmers do not enter the pen to conduct detailed tail lesion inspections, and are likely to only act when clear signs of tail biting are observed. By using this practical definition of tail biting outbreak in this chapter, it makes the results applicable for use on farm.

Collecting data across two studies enabled us to record enough tail biting outbreaks so that statistical analysis was possible, and there was no difference in terms of the effectiveness of intervention protocols to overcome outbreaks between the two, so data were pooled together for analysis. However, these two studies were carried out under different experimental designs and treatments, and thus this point has been included in the analysis and discussion.

Since the intervention protocols were tested concurrently with the main studies, we need to consider possible crossover effects. Due to ethical concerns, when tail biting events took place, necessary actions should be taken. The two experiments also benefitted from the interventions in that the original sample sizes were maintained, since we incorporated reintroduction of the animals into their home pens as part of the intervention strategies. However, we understand this creates complexity in interpretation, and needs to be accounted for. In Chapter 5, although the number of outbreaks and intervention methods used did not differ between treatments, the consequences of intervention methods did result in differences between treatments (e.g. the number of pigs removed), thus this was further accounted for in analysis, and discussed. On the other hand, in Chapter 6 there was no difference between treatments in terms of the number of outbreaks or the consequences of the intervention methods, and therefore there were fewer confounding factors.

Correction: on page 264 (page 13 of the published article), the last word on line 4 from the top should read “ranges” of conditions.

Chapter 8 General discussion

"An intact curly tail may well be the single most important animal-based welfare indicator for weaned, growing and finishing pigs…it stands for high-quality management and respect for the integrity of the pig."
(Spoolder et al., 2011)

8.1 Main findings

This thesis aimed to investigate practical strategies to manage tail biting in pigs housed in fully-slatted systems. The starting point was to identify suitable enrichment materials that are compatible with fully-slatted floors. Wood is an organic material which is easily available locally in Ireland and is preferred by producers (Haigh and O'Driscoll, 2019) and therefore was selected to be the main focus at the start of our investigation. Currently, this is still the first study to compare different wood species with regard to various properties (length, weight, dimension, moisture and hardness) in order to understand how these properties may affect how much pigs' interact with them. Based on the findings from Chapter 3 and 4, spruce, which is the softest wood species used in this study (but does not necessarily contain the highest moisture level), was most frequently used by the pigs and consumed most quickly. On the other hand, the soft rubber floor toy was also used by the pigs for a similar duration as spruce. Although inorganic materials are usually considered inferior to organic materials (European Commission, 2016b), our results suggest that this is was not necessarily the case.

A more in-depth method of observing behaviour in Chapter 4 showed that the spruce post and the rubber toy not only attracted the pigs' overall attention longer, but that the average interaction bout length was also longer compared to larch and beech. Moreover, the overall higher duration of interaction was not attributable to only certain pigs that were particularly motivated to use the enrichment, but rather the interaction was widely spread out within a group. This demonstrated that an enrichment item with the right characteristics can not only attract pigs for longer, but can also permit use by most pigs in a group. The enrichment to pig ratio used in

Chapter 4 is 1:7, and a study showed that when the pig to enrichment (a pine post) ratio increased from 1:9 to 1:4.5, pigs' interaction with the enrichment also increased (Larsen et al., 2019). However, another study reported no difference in interaction with a hanging plastic toy at either a 1:32 or 1:8 ratio (Scott et al., 2007b). The authors concluded this lack of difference was due to low stimulation from the toy. They also did not record higher aggression from competition for enrichment access, whereas in Chapter 4, we found higher aggression at the spruce post than beech. This may suggest the enrichment material we assessed was more valuable to pigs. Further study is still needed to determine the optimal enrichment to pig ratio when using point-source items that are attractive to pigs.

In Chapter 3, where 4 species of wood were compared, there was no difference in physical scores (tail and ear lesions, tail postures and tear staining scores) or in damaging behaviours. In Chapter 4, however, pigs with spruce had slightly higher tail lesion scores and a moderate correlation was found between damaging behaviours and enrichment use. This may suggest that when the enrichment stimulates pigs' foraging need, yet is insufficient to consummate it, it could generate more biting behaviours which then become redirected towards other pigs (Duncan, 1998). The different results from these two studies could be due to different behaviour sampling methods. Nevertheless, in the first two studies (**Chapter 3 & 4**), docked pigs were used and the overall level of tail biting recorded in both trials was low, without any major tail biting events occurring. This is in line with many previous studies, which have shown that tail lesions and tail biting behaviours are more prevalent in undocked than docked pigs (Lahrmann et al., 2017). These two studies provided a foundation for the basic investigation into using wood as enrichment. Although the effectiveness of wood at reducing the risk of tail biting cannot be fully ascertained, these studies provided the opportunity to assess the use of single point-source enrichment among groups of pigs, and under commercial rearing conditions. The next step was to assess how effective the enrichment items were in reducing the level of damaging behaviours performed in undocked pigs.

In Chapter 5 undocked pigs were reared on fully-slatted floors using the more preferred enrichment items identified in the previous two studies (**Chapter 3 & 4**), the spruce post and rubber toy, in combination with one of two levels of dietary fibre (standard fibre: weaner 3.7% and finisher 5.9%; high fibre: weaner 5.3% and finisher 11.6% of crude fibre). In order to simulate conditions on most Irish pig farms, only one enrichment item per 14 pigs was provided with a stocking density similar to commercial practice (0.45m^2 for growers up to around 30kg and 0.69 m^2 for finishers up to around 110kg). There was a high level of tail biting, with a large number of animals removed at least temporarily from the trial to control tail biting. Additionally, pigs fed with the higher fibre diet had the worst tail lesion scores, and performed more tail biting, contrary to our hypothesis that an increased fibre content would increase satiety and lower activity level. This showed that simply increasing the fibre level in pigs' diet, when only a minimum amount of enrichment is provided, is not sufficient to reduce the risk of tail biting to an acceptable degree, and more complex strategies are needed.

A pilot study not included in the current thesis (Chou et al., 2019) was conducted after the previous study (**Chapter 5**), in order to find out if it is even possible to rear undocked pigs on fully-slatted floors with multiple enrichment items that are compatible with the housing system (i.e. no floor substrate present), without altering any other aspect of the infrastructure (with a slightly lower stocking density: 0.52m^2 for growers up to around 30kg and 0.8 m^2 for finishers up to around 110kg). The results were extremely positive; only 1 out of 96 pigs had tail loss, and no tail biting outbreak occurred. This moved the research towards the direction of providing multiple enrichment items to pigs, but compared different replenishment frequencies to balance between pigs' needs and feasibility for farmers, and led to the development of the last study (**Chapter 6**). This expanded on the pilot study, and focused on the presence or absence of pre-weaning exposure to enrichment, as well as different replenishment frequencies ("High", "Medium" and "Low") when multiple slat-compatible enrichment items were provided at a similar level to the pilot study. The level of tail biting was greatly reduced compared to Chapter 5, and although no difference in physical scores was found between treatments, “Low” pigs performed more damaging behaviours combined (tail and ear biting, biting other body parts, belly-nosing, aggression and mounting). The average daily gain during the finisher stage was higher in “High” pigs, implying that frequent enrichment replenishment can improve performance. The economic modelling in Chapter 6 suggested that undocked enriched pigs could generate a higher net profit margin than docked minimally-enriched pigs in a well-managed farm, which can potentially cover the cost of extra enrichment. This demonstrated that there are as yet under-appreciated potential economic benefits to keeping undocked pigs with plenty of enrichment provision, as well as the more recognised benefits for pig welfare.

Despite the focus on strategies to reduce tail biting, tail biting outbreaks can still happen sporadically (D’Eath et al., 2014). Therefore, further exploration on how best to intervene once a tail biting outbreak has started was conducted. Data were collected during the last two studies (**Chapter 5 & 6**) when undocked pigs were used, as there was a higher risk of tail biting than in the previous chapters. Prior to the commencement of the experiment described in Chapter 5, a well-defined outbreak intervention protocol was designed and developed, and using this protocol, data were collected on tail biting outbreaks using a structured methodology to assess three different intervention methods (removing biters, removing victims or adding ropes) in a 3-step protocol. Across all methods, eighty percent of the outbreaks were brought under control. Removing animals resulted in a longer outbreak duration than the addition of ropes, as the re-introduction step was considered a part of the protocol. However, disregarding the duration of the intervention method, none was more successful than any other at stopping an outbreak. In fact, the proportion of biters and victims involved in the outbreak had a stronger effect on whether an outbreak could be successfully controlled; this highlights the importance of prompt intervention. By incorporating a multi-step approach, even including reintroduction of animals back to their home pen after removals, the designed intervention protocols can be applied on commercial farms.

Below is a summary of the key findings in the thesis:

- Different species of wood result in a different frequency of interaction from pigs.
- Spruce, which is a soft wood species, generated more interactions from pigs, longer interaction bouts and more evenly distributed interactions within a group, than the harder wood species investigated.
- A soft rubber floor toy can generate a similar amount and pattern of interaction as spruce, when the design of the toy prevents excessive soiling.
- A single enrichment item per 14 pigs, regardless of dietary fibre level, was not sufficient to reduce the risk of tail biting in undocked pigs on fully-slatted floors.
- An adequate enrichment to pig ratio (8:12 in this thesis) including items with biologically relevant properties, such as some forms of loose materials, can reduce tail biting risks in undocked pigs on fully-slatted floors with potential advantages in performance that can compensate for the extra enrichment cost.
- Intervening in tail biting outbreaks using a 3-step protocol, which alternates between removing biters, removing victims or adding ropes, and which also includes reintroduction of animals, can be successful and practical on farm.

8.2 Novelty of the approaches

Chapter 3 was the first study to our knowledge to compare different species of wood as environmental enrichment for pigs. Wood has been very commonly used in research and commercial studies as an enrichment material; however in previous research, either the species used were not reported (Beattie et al., 1998; Tönepöhl et al., 2012; Trickett et al., 2009; Zonderland et al., 2003), or it was reported with no reference to its hardness or any other relevant properties which could affect pigs' motivation to use it (Cornale et al., 2015; Nannoni et al., 2018, 2016; Telkänranta et al., 2014a). It is understandable that it may not be feasible to always include detailed descriptions of the wood species and their properties, but these data are necessary to develop a robust interpretation of results, and consequently a better assessment of its effect on the proposed outcome. This is attested by the results from Chapter 3 and 4, which clearly demonstrate the species of wood will indeed have an effect on how much the pigs interact with it. If the species or hardness are unknown or cannot be determined, the weight loss and replacement rate of the wooden material are also good indicators of how destructible and ingestible it is, and should be measured and presented to evaluate how much the enrichment was used, as a supplementary assessment to behavioural data. Indeed, unlike studies where wood is investigated, in studies on the provision of straw and other loose materials, it is common that the weight of the materials is reported. Throughout the thesis, all data pertaining to the rate of use of enrichment materials were recorded and provided, as the data supplement behavioural data and lesion scores, and thus improved our ability to interpret the results.

This thesis includes first post-mortem examinations to be carried out to investigate the presence of possible oral lesions that may arise from using wood as enrichment for pigs. During the survey carried out by Haigh and O'Driscoll (2019), producers raised concerns about splinters caused by providing wood to pigs, even though currently there's no scientific evidence supporting these concerns. I examined the tongue and gum area on 280 carcasses and did not find oral lesions that could be related to using any wood species, and there were no differences between treatments with regard to any damage that was visible. Thus, based on the current results, wood appears to be a safe material to use as enrichment for pigs without causing them any obvious health issues. A systematic categorisation of different types of pigs' oral lesions, combined with an examination of toxicology and the digestive tract would provide a fuller picture of any potential hazards associated with wood-based enrichment.

To our knowledge, this is also the first study to investigate the effect of dietary fibre on damaging behaviours in growing-finishing pigs which are fed *ad libitum*. The benefit of high fibre is more understood in terms of reducing the performance of feather pecking in laying hens and of stereotypic behaviours in pregnant sows, but there was no information in the literature regarding growing-finishing pigs. Studies of fibre in growing pigs' diet have mainly focused on pigs' performance and gastric health. Altering pigs' diet by increasing fibre to manage tail biting would be easier and less costly to implement without structural changes to the current housing and practices than providing more, or new types, of enrichment. However, this study showed that pigs which consumed a high fibre diet performed more tail biting behaviour, and had higher tail lesion scores, than those on a standard grower and finisher diet while there was limited foraging material in the environment. After the completion of this thesis, a latest study (Naya et al., 2019) explored high dietary fibre in the weaners' diet from 4 to 7 weeks of age using commercially formulated high fibre diet. The pigs received a small amount of straw meals as enrichment. Equally, they did not find any effect of high fibre diet on weaners' tail biting behaviour. Studies have suggested that dietary fibre might reduce pigs' activity level to a greater extent when restrictedly-fed pigs were kept in an enriched environment with straw bedding (Bolhuis et al., 2010). Therefore, this study does not enable us to conclude that high dietary fibre would increase pigs' damaging behaviours regardless of environment. Further investigations on the interaction between dietary fibre and environment are needed.

In Chapter 6, a combination of eight enrichment items with different properties that are biologically relevant to pigs was used. The majority of enrichment studies have focused on comparing between types of loose materials or point-source items, usually with only one type available for a group of pigs, and have rarely used a combination of different items together. This has been done to objectively evaluate the effect of each item independently, without confounding the results. However, this methodology undermines the effect of enrichment materials when different items are provided together, especially for point-source items, since a range of properties, which may vary across items, are valued by pigs (van de Weerd et al., 2003), and may retain pigs' attention when presented all at once (Telkänranta et al., 2014a; Zwicker et al., 2013; Trickett et al., 2009). In terms of reducing tail biting in undocked pigs, this is especially important since the range of properties provided by different point-source items could be more effective in reducing tail biting than a single item, or a higher quantity of the same item.

The tail biting outbreak intervention protocol described in Chapter 7 was novel in two ways: a) by using a multi-step protocol combining three different methods (removing biters, removing victims, adding ropes) rather than comparing single methods one by one (this was the methodology used in previous studies in outbreak intervention (Lahrmann et al., 2019; Zonderland et al., 2008), and b) by including reintroduction of animals to their home pens as a criteria for a successful intervention. This protocol increased the likelihood of the protocol being successful (only 50% of outbreaks terminated after only one intervention was applied, as opposed to 80% after three), and is also more applicable to commercial conditions as it is not limited to one method. Including the element of re-introduction also increases commercial relevance since this reduces the pressure of the need for extra space to permanently house animals once they have been removed.

8.3 Limitations

In the first study (**Chapter 3**), the risk of tail biting on the commercial farm with fully-slatted floors was considered to be relatively high, so tail docking was carried out on the farm. Thus, in order to keep the disturbance of the normal farm practices to a minimum, docked pigs were used. In the second study (Chapter 4), due to logistics, the pigs were sourced from an external breeding farm, and therefore they were also tail-docked. Using docked pigs limited our ability to assess tail biting outcomes. However, as the main aim of these two studies was to compare use of different enrichment items, with a particular focus on different species of wood, the docked tails were unlikely to have affected the amount of interaction with the enrichment materials. It also enabled the investigation on enrichment without being confounded by more severe tail biting and the interventions that needed to be carried out. Nevertheless, even though the amount of tail biting was evaluated in behaviour observations, and scoring of tail lesions was included in the studies, these measures did not provide as much insight into the risk of tail biting as the subsequent chapters, due to its overall low occurrence. Indeed, more ear than tail biting behaviour was recorded in both studies. These two studies did, however, form the foundation of our investigation into using wood as an enrichment material for undocked pigs. Indirectly, they reaffirmed that tail docking is still commonly practiced in Ireland for good reason at the moment, and that complex solutions are needed to bring forward changes.

During the course of the PhD project, the main assessment measures were physical scores including tail and ear lesions, tear staining and tail postures, behavioural recordings, and enrichment measurements. The only physiological measure used was salivary cortisol concentration, which was included in Chapter 4. Salivary cortisol is still a non-invasive and commonly-used physiological measure of arousal, which could provide insight into the level of stress that pigs experience (Cook et al., 1996). However, it is most likely not useful for detecting differences in chronic stress levels caused by provision, or lack, of appropriate enrichment materials, especially when the sampling frequency is limited to once every two weeks in the morning, as in this study. When de Jong et al. (2000) compared between straw-enriched and barren-housed pigs, the barren pigs showed a blunted circadian rhythm in terms of salivary cortisol, suggesting that they may have been chronically stressed. To assess the potential presence of chronic stress, taking repeated samples from the same individuals is necessary. In Chapter 4, the *ad libitum* feeding strategy might also have interfered with the results. Nonetheless, salivary cortisol in pigs is still the most convenient and economically viable option in terms of sample collection and analysis. For these reasons, this is the only physiological measure used in this thesis, and unsurprisingly, the results did not provide much insight into the effect that the enrichment treatments had on the pigs. The investigation may have benefitted from other physiological measures of stress (e.g. hair cortisol or faecal corticosteroid), since stress is a factor which can increase the risk of tail biting (Brunberg et al., 2016; Schrøder-Petersen and Simonsen, 2001; Taylor et al., 2010; Valros, 2018) or could occur as a result of being bitten (Munsterhjelm et al., 2013a;

Winanda W. Ursinus et al., 2014). Chronic stress itself is also an indicator with regard to the animal's long-term wellbeing (Moberg and Mench, 2000). Nonetheless, these non-invasive measures still have similar limitations as salivary cortisol in their interpretation if only single measure is used, since cortisol as a hormone can be affected by many other internal or external factors. Considering the main focus of the thesis is to tackle the issue of tail biting using management strategies, mainly enrichment and diet, use of animal behaviour and measurement and physical scores provide sufficient evidence for the assessments in the thesis. The result of salivary cortisol in Chapter 4 did, however, demonstrate the importance of choosing the correct physiological measures and methods to obtain valid and useful information.

In Chapter 5, which compared the effect of standard and high fibre diets on damaging behaviours, the method of behaviour observation was pen-level all-occurrence continuous sampling for five minutes, with each behaviour recorded as a frequency, due to the constraint of labour and time. With this methodology, feeding behaviour was not included in the ethogram, since it requires recording of individual pigs and duration of the behaviour. Contrary to the hypothesis, pigs receiving the high fibre diet performed more tail biting behaviours and had higher tail lesion scores. One of the possible explanations for this could be the effect of increased fibre level with regard to feeding time; a high fibre diet may result in prolonged feeding bouts, which could have increased 'queuing' at the feeder, when the feeder used was single-spaced. These stressors could in turn have increased the risk of tail biting. However, without data on feeding behaviour, it is not possible to determine whether this explanation was accurate. General activity level was not recorded either, so we were not able to confirm whether high fibre diets led to reduced activity. Therefore, without further verification of how dietary fibre altered pigs' feeding patterns, it is difficult to conclude how it directly or indirectly affected tail biting behaviours.

In Chapter 6, only hanging items were used as pre-weaning enrichment. The heat pad in the farrowing pen is a solid floor area, but due to concern over hygiene and maintenance, loose materials were not used. This might have reduced any positive effects of early exposure to enrichment, as there is some evidence that the provision of loose materials pre-weaning can have a positive effect on pigs' oral manipulative behaviours later in life (Telkänranta et al., 2014b; Munsterhjelm et al., 2009). Moreover, analysis of piglets' behaviours in the farrowing house were not included in the current PhD thesis due to time constraints and the scale of the PhD. In another study (Grocott, 2018), which the author was involved in, different measures were taken from pre-weaning piglets from batch three and four in Chapter 6. Further analyses linking pre-weaning observations and post-weaning tail biting outcome are expected to be conducted in the future to understand better the influence of pre-weaning experience.

Additionally, in Chapter 6 we were successful in reducing tail biting by using an enrichment provision protocol consisting of multiple items with different characteristics. The pigs showed an overall higher level of interaction with the grass in the elevated rack, and "high" replenished pigs consumed more grass and performed less damaging behaviour combined. This showed that the presence of grass was crucial, but it is not known how much of the overall result was due to grass. Studies have shown that pigs in general preferred loose materials to point-source items (van de Weerd et al., 2009), but others also suggested simply using loose material dispensers with limited access was not sufficient to reduce tail biting in undocked pigs (Holling et al., 2017; Veit et al., 2016). Our results did show that in "low" replenished pigs, the interaction with all other items than grass was higher, which suggested that when access to grass was limited, the presence of other point-source items was meaningful as well (For "High" pigs, the frequency of interaction was 0.017 ± 0.001/pig/min with grass and 0.022 ± 0.001/pig/min with all other items, whereas for "Low" pigs it was 0.011 ± 0.001/pig/min with grass and 0.027 ± 0.001/pig/min with all other items). According to the latest EC recommendation (European Commission, 2016a), loose materials are considered "optimal" and should be constantly available, whereas other “suboptimal” items can be used in company with the loose materials. However, practicality is always a constraint. Further investigation is still required to determine what the “optimal” enrichment provision is on fully-slatted floors, whether by a better access to loose material via dispensers only, or by a sufficient access to plenty of non-particulate but biologically-relevant point-source items with limited loose material. It is also important to define the “optimal” enrichment to pig ratio. After all, the definition of being “optimal” in commercial pig production should account for the pigs’ biological needs, the effectiveness of reducing damaging behaviours and also the practicality in management.

Different lesion scoring systems were used across studies, especially from Chapter 3-5. This followed a progressive development of the experimental studies, the context where the experiments took place and the training and competence of the experimenter. In Chapter 3, the study took place on a commercial farm and at the same time I was following a post-doctoral researcher, who was also conducting an experiment on the same farm, for training of lesion scoring as well as behaviour observation. The housing condition was difficult to score lesions inside the pen (as shown in the supplementary file in Chapter 3), and therefore a simpler system was used (0-3 scale, Hunter et al., 1999) for efficiency and safety. In the next study (**Chapter 4**), on the Teagasc research farm, there was greater flexibility to test the feasibility of the then newly-developed, more detailed tail lesion scoring system (by the FareWellDock consortium), which scores separately the tail wound and the presence of blood on the tail. In order to keep a consistency between studies, both the Hunter system and the FareWellDock system was used concurrently. After this study, I became more competent in scoring tail lesions and the FareWellDock system proved to be more useful and informative so that it was subsequently used in Chapter 5 and 6. Due to the different tail scoring systems used, and the fact that pigs had different tail lengths, it made it inappropriate to compare results across all studies included in this thesis.

Similarly, different methods of behaviour observation were also used. In Chapter 3, a simpler 3-minute observation was used on the commercial farm. This was to adapt to the condition on the commercial farm and also as part of the training at the beginning of the project. In Chapter 4, the main aim of the study was to understand better how pigs interact with the enrichment. With the support from the research facility, video recording was possible, and therefore video observation was used instead of live observation. In the following studies (**Chapter 5** and **6**), similar live behaviour observation within a short duration was used, albeit with different frequencies and levels of recording. This reflected the gradual development of my competence as the single recorder of all behaviour observation but also the limitation in time and labour with different tasks in different studies. Nevertheless, this indeed created difficulties in comparing results across studies, and caution was exercised when such comparison was made. Additionally, a 5-minute live observation of pig behaviours also has constraint in itself since some behaviours happen in short and sporadic bouts, especially for damaging behaviours such as tail and ear biting. However, due to the time and labour constraint mentioned earlier, the experimental protocols were designed in a way to compromise between a maximal data collection and a reasonable time management. In Chapter 6, continuous video recordings were taken for the majority of pigs at different ages, and in the future these videos could be further investigated to gather more data to evaluate the validity of the study.

In all studies in this PhD thesis, no negative control (without enrichment) was used. Using a negative control is advantageous to demonstrate the effect of the treatment provided. However, it is a legal requirement to provide some form of materials for pigs to manipulate under current legislation (EU 2008/120/EC), and in the existing literature there is sufficient evidence of the negative consequences and outcomes that would take place if pigs were housed in a barren environment (Beattie et al., 2001, 2000, 1995; Bolhuis et al., 2005; de Groot et al., 2000; Klont et al., 2001; van de Weerd et al., 2005). Thus, based on the principle of refinement in experimental design, we chose to compare between enrichment items and treatments applied, without using a negative control. It would be interesting to compare our experimental results with a positive control (e.g. using straw bedding which is considered the most biologically relevant enrichment for pigs), but unfortunately it was not feasible on the fully-slatted research farm where the experimental work took place. Enrichment studies assessing the effectiveness of reducing damaging behaviours could achieve their aim by utilising treatment comparisons without using a negative control, but a positive control should be included where possible to give a full understanding of how effective the enrichment treatment in question is. In the current thesis, without a negative control in the studies, it does call for more cautious interpretation of the results, without knowing the exact consequences when no treatment was applied.

8.4 The future of fully-slatted systems

Fully-slatted flooring systems benefit manure removal and efficiency, and maintain good hygiene standards in commercial units. However, these systems create difficulties in providing materials for pigs to manipulate, restrict pigs' need to express foraging behaviour, and reduce their overall activity level (Scott et al., 2007a, 2006a). Hence, slatted floors have been identified as a major risk factor in tail biting in epidemiological studies (Grümpel et al., 2018; Taylor et al., 2012), probably because they are associated with a lack of enrichment. By installing chopper filters (Ryan, 2005) or by using more advanced techniques to separate solid and liquid manure (Jones and Cherruault, 2011), some blockage issues can be resolved, and pig production can even be more energy efficient (top tup, 2008). Thus, fully-slatted systems themselves may not be the main culprit when it comes to lack of appropriate enrichment provision, but the question is rather why these improvements have not been made in most farms. The answer is likely due to mainly economic concerns, as well as the lack of better communication on how to resolve this issue and make improvement relevant to each farm. Once a pig production facility is built, the "system inertia" will be stronger since the investment to change the slurry infrastructure is greater than modifying feeding or penning (D'Eath, 2015).

Other drawbacks exist regarding the use of fully-slatted floors. The benefit of easy manure handling stored beneath the flooring can become the source of higher ammonia levels in the housing compared to a straw bedded system (Philippe et al., 2011), although there is also some conflicting evidence (EFSA, 2005; Pereira et al., 2011). Slatted flooring is associated with a higher occurrence of respiratory diseases (EFSA, 2005; Scott et al., 2006a), which is itself also associated with tail biting (Kritas and Morrison, 2007; van Staaveren et al., 2016). During manure removal in fully-slatted systems, peak ammonia levels were reported (EFSA, 2005), and therefore well-designed drainage, good ventilation and climate control is needed to achieve the benefit of reduced ammonia level in slatted housing (EFSA, 2005; Pereira et al., 2011; Van Ransbeeck et al., 2013). The living environment of the pigs is also the working environment for the stockpersons, and the housing conditions thus not only affects animals but also humans, which corresponds with the "one health," "one welfare" concept (Dawkins, 2017; Pinillos et al., 2016). Moreover, pigs are observed to use different areas of the pen for different purposes, such as defecating and lying, and the use of fully-slatted floor obscures this separation, although space allowance is also relevant to this point (EFSA, 2005). Different floor types may have different risks for certain types of foot lesions (Gillman et al., 2009; KilBride et al., 2009), but an overall higher prevalence of floor-related disorders on limbs was found on slatted floors compared to solid floors (Gillman et al., 2009; Jørgensen, 2003; KilBride et al., 2009; Mouttotou et al., 1999), especially on concrete slats where sharp edges can be common. Some studies concluded that partly-slatted floors with some forms of bedding may be a good compromise in indoor housing systems (KilBride et al., 2009). Scott et al. (2006a, 2007a) compared straw-bedded with fully-slatted systems and concluded that while fully-slatted systems improved hygiene and disease occurrence related to enteric tract and porcine circovirus, behavioural expression and limb health was better in straw-bedded system. It is difficult to make direct comparisons between two very different housing systems, especially when fully-slatted housing to date is normally presented as a barren environment. Future studies should compare between these housing types when biologically relevant enrichment that can satisfy pigs' natural behaviours is provided to understand the impact of floor type alone.

Based on the estimation of pig production in the EU in 2005, fully-slatted floors were found in 67% of weaner and 44% of finisher housing (EFSA, 2005). This number can be foreseen to decrease since Sweden, Germany, Denmark, the Netherlands, Finland and Switzerland, have either enforced national legislation on abolishing the use of fully-slatted floors, or have entered a transition period in phasing out their use (European Commission DG SANTE, 2016; Mul et al., 2010). These changes reflect the view that the capacity to incorporate the use of loose materials in newly-built housing systems is essential. Although to challenge the fully-slatted system is not the aim of this thesis, the constraints and limitations of this type of housing system need to be acknowledged. There is a need for further discussions on whether this system has essentially unethical flaws to prevent pigs from performing natural behaviours, e.g. the inability to provide loose substrates on the ground to satisfy the pigs' innate rooting behaviour. It is uncertain if slatted floors will cease to be used in the future, but nevertheless, while they are still in use in global pig production, at least our study has shown that there are ways to mitigate the issue of tail biting by providing adequate enrichment that are fully slat-compatible. There is ample scope for improvements to management practices in this housing system, such as by providing sufficient enrichment as demonstrated in Chapter 6 and lowering stocking density, to enable rearing of undocked pigs, and improve animal welfare standards.

8.5 Reflections and the way forward

During the course of the PhD, one crucial development which is not easily reflected in the chapters, is that by rearing undocked pigs and experiencing tail biting first-hand, I have become much more capable of identifying the signs of tail biting, and carrying out appropriate interventions when necessary. Compared to the first study (**Chapter 5**) when undocked pigs were used, I've gained more competence and confidence in caring for undocked pigs. Although the outbreak control strategies were implemented as per the pre-determined protocol, I also obtained experience in dealing with outbreaks which occurred in non-trial pens of undocked pigs on the farm. With the increased training in observing early signs of tail biting (e.g. by tail postures) and identifying different types of biting as described by Taylor et al. (2010) and Valros (2018), I was able to intervene with tail biting more efficiently by early intervention and using interventions that were more fitting (e.g. removing biters when it is "obsessive" biting, checking feeder failure when "sudden forceful" biting occurred and provided more enrichment items, removing victims if bitten pigs were unresponsive). The importance of this learning process has also been reported in other studies (Veit et al., 2016), which is crucial for the farmers to gain confidence in facing tail biting, through learning by doing.

In studies looking at farmer' attitudes in improving practices in terms of animal welfare, the perceived benefits of the practice had a strong influence on whether farmers are willing to change (Bruijnis et al., 2013; de Lauwere et al., 2012; Kauppinen et al., 2012; Peden et al., 2018). It is therefore also important to demonstrate the benefits of providing enrichment and keeping pigs' tail undocked, as part of the findings of the PhD. The addition of the economic analysis in Chapter 6 will help to reassure producers that although providing enrichment seems costly, the benefits for the pigs' performance, health and welfare may outweigh the cost and generate a higher profit in the long run. The improvement in terms of the amount and severity of tail biting outbreaks from Chapter 5 to Chapter 6 illustrates the possibility of rearing pigs with undocked tails by increasing the quantity and quality of the enrichment items provided, without fundamentally changing the housing system, although the change in stocking density, weather, and capacity to manage tail biting should also be taken into account.

In Finland, tail docking has been illegal since 2003. However, according to their survey on Finnish farmers (Valros et al., 2016), most producers would not consider going back to docking even if it were made legal again. Ultimately, as the ban on tail docking is foreseen to be enforced more extensively in Europe in the near future, this PhD thesis has demonstrated that there are practical steps that can be taken to reduce the risk of tail biting on fully-slatted floors that can be implemented immediately. There are ways to provide meaningful and effective enrichment to undocked pigs, using easily available, locally sourced and less expensive items with a little creativity and understanding of how enrichment functions, and these are some of the first steps that the producers can take in starting to try rearing undocked pigs. The quotation at the beginning of this chapter argued that the tail of a pig can be an indicator not just of the status of the pig itself, but also of the health of the herd in general. By conducting this investigation on seeking feasible solutions to rear undocked pigs that can be compatible in the housing systems as status quo, the ultimate goal of this thesis is to inspire and contribute to changes to current tail docking practices.

Some areas of research that could not be included within the scope of the PhD but would be important to follow up on include the following:

1. A thorough cataloguing of post-mortem oral lesions is needed to establish an in-depth lesion scoring system. During the examination process, I found it difficult to determine the cause of the lesions, but if post-mortem examination could be conducted at different age points, it may pinpoint what exactly contributes to development of oral lesions, e.g. pen fixtures. Oral examination could also be accompanied by intestinal examination or faecal sampling, to look for possible residues from the enrichment materials provided (such as wood pieces, hessian, rubber, or other inorganic substances). Furthermore, toxicological studies could also be useful to determine if enrichment ingestion has a negative effect on physiological parameters.
2. The effect of dietary fibre on growing-finishing pigs still needs further investigation, especially combined with biologically relevant enrichment provision such as forms of rooting materials and detailed observation of activity level and feeding behaviours.

3. It is crucial to calculate the labour cost of enrichment maintenance under strategies similar to the complex enrichment provision proposed in the thesis, so that there is a complete cost analysis. Economic modelling comparing different rearing scenarios, such as the one conducted in the study (**Chapter 6**), should also include an estimate of the cost of tail biting (e.g. medical cost and space) and the saving of labour from not practicing tail docking.
4. In the thesis, the successful enrichment strategy shown in Chapter 6 was using eight various items for 12 pigs. Pigs showed a preference for the grass in the elevated rack more than anything else, both in the weaner and the finisher stage. Within the scope of the thesis, it was not possible to explore how much effect came from the loose materials alone and how much from the enrichment to pig ratio. Further research is needed to examine the effectiveness of reducing damaging behaviours and stimulating enrichment interaction when providing multiple and various biologically-relevant point-source items without a dispenser of loose materials, or when providing only dispensers of loose materials but with sufficient access for most pigs in the group.
5. To understand more about the effectiveness of the tail biting outbreak intervention protocol proposed to overcome TBOs, more analyses on the combination of different intervention methods are needed. It will also be meaningful to categorise different types of tail biting (e.g. sudden forceful, two stage or obsessive) and evaluate the effectiveness of different methods accordingly. These require large scale data collection across studies or a meta-analysis.

8.6 Conclusions

This PhD thesis continued the line of research on tail biting and enrichment, and it confirms previous research that it is crucial to think about the properties of enrichment before providing it to pigs. Even within the category of “wood,” outcomes can be different because of the different properties of various wood species. Softer wood species can attract more interaction from pigs, as well as well-designed softer rubber toys. Moreover, the quality (loose material dispenser was most preferred), quantity (enrichment to pig ratio) and the presentation of a range of enrichment items are all important points to consider. To rear undocked pigs on fully-slatted floors, it is not enough just to increase the dietary fibre without also improving the environment. An enhanced enrichment strategy could be more effective in reducing the level of tail biting, both in terms of less frequent damaging behaviours and lower percentage of pigs with tail loss. Although tail biting still occurred, the outbreak intervention protocol developed can help effectively intervene with it, especially when done promptly. Most importantly, the enhanced enrichment strategy with undocked pigs not only helped improve tail biting outcomes, but also the pig performance and the overall profit margin. It is a win-win for the pigs and producers, and this thesis showed a positive potential to improve current management systems to meet the needs of the pigs, the legislation and the industry.

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